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An Elementary Treatment of Vibrating Strings

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STANDING waves are most frequently analyzed as arising from two equal wave trains traveling in opposite directions. For example, if a string has a linear density of m gram/cm and is stretched by a force of F dynes, the speed v of a wave in the string is $(F/m)^{\frac{1}{2}}$ cm/sec. Then, if the length of the string between stops is L cm, standing waves of period $2L/vn$ (n being any integer) are possible. In addition to providing a derivation for the period of a vibrating string, such a presentation very properly indicates the relation of standing waves to other wave phenomena.

A supplementary treatment is useful in elementary work. To students the procedure just outlined appears somewhat artificial; many prefer a method that makes a more direct use of the elementary principles of mechanics. Now, the parts of the string execute simple vibratory motion. Hence, the most direct treatment is one based on the familiar principles of such motion. This treatment yields the same expression for the period as the preceding one, and also emphasizes the relation of standing waves to simple vibratory motion. Approach to the theory of vibrations in uniform strings through consideration of weighted strings has been used in advanced texts,[1] but the fact that elementary students are in a position to profit by a modification of such a treatment does not appear to be generally recognized.

Case 1.—We may start with a very simple problem, which involves the extreme case of a nonuniform string, one in which the total mass mL is concentrated at the center (Fig. 1). Since a displacement of y cm for the mass gives rise to a force of $4Fy/L$ dynes, provided y is small compared with L, the expression for the period P as obtained from the formula for simple vibratory motion is,

$$P_1=2\pi\left(\frac{mL}{-F'/y}\right)^{\frac{1}{2}}=2\pi\left(\frac{mL}{4Fy/yL}\right)^{\frac{1}{2}}=\pi L\left(\frac{m}{F}\right)^{\frac{1}{2}}.$$

The ratio of this result to that for the corresponding uniform string is $\pi/2$ or approximately 1.57. Further division and subdivision of the mass results in closer and closer approximations to the result for a uniform string. It will be noted that this weighted string has but a single mode of vibration, whereas the uniform string has both a fundamental frequency and various harmonics.

Case 2.—For a closer approximation to the behavior of a uniform string, consider the total mass of the string to be divided into two parts each of mass $mL/2$, one located at a distance $L/4$ from one peg and the other at $L/4$ from the other (Fig. 2). To excite the fundamental only, the masses

[1] See, for example, Slater and Frank, *Introduction to Theoretical Physics* (McGraw-Hill, 1933), sec. 80.

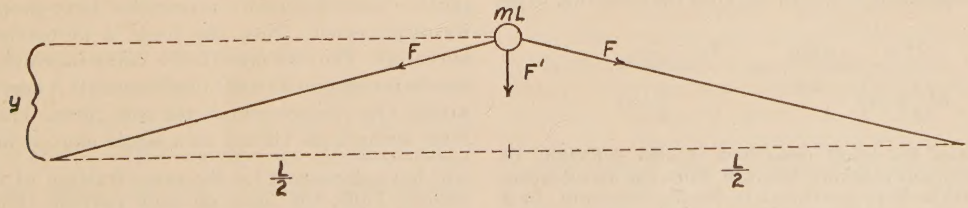

FIG. 1. Case 1.

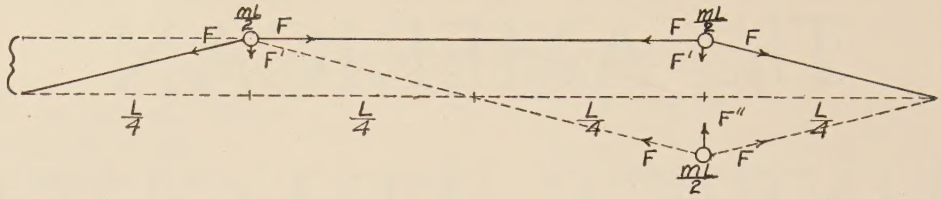

FIG. 2. Case 2.

may be displaced transversely through a distance y in the same direction and both released at the same time.

The period of the fundamental as computed from the formula for simple vibrations is given by

$$P_1 = 2\pi(mL^2/8F)^{\frac{1}{2}} = 2.22L(m/F)^{\frac{1}{2}}.$$

This expression is a fair approximation to that for the fundamental of the uniform string, since it yields values that differ from those for the latter by only 10 or 11 percent. Furthermore, in this case two modes of vibration are possible. If the mass points are displaced equal distances in opposite directions and released simultaneously, we have a second frequency which corresponds roughly to the first harmonic of the uniform string. The expression for the period is in this case

$$P_2 = 2\pi(mL^2/16F)^{\frac{1}{2}} = 1.57L(m/F)^{\frac{1}{2}}.$$

Since the period of the first harmonic of the uniform string is given by $L(m/F)^{\frac{1}{2}}$, the relative error in the period of the first harmonic in this case is just the same as that for the fundamental in Case 1. In fact, our treatment of the first harmonic in this case is identical with our treatment of the fundamental in Case 1, so it is not an accident that the results are the same. In this method of treating the vibrations of wires or strings the period corresponding to the highest frequency will always differ from that of the corresponding frequency for the uniform string in the same proportion.

Case 3.—Consider now three masses, each $mL/3$ gram, located along the string at distances of $L/6$, $L/2$ and $5L/6$ from one end. The fundamental is excited by displacing all the masses in the same direction by such amounts that when released simultaneously all will execute simple vibratory motions of the same period. To accomplish this, it is obviously necessary that the forces on the various particles be proportional to these initial displacements.[2]

Looking at Fig. 3, we see that the force on the central particle is $F_1 = 2Fy_1/(L/3) = 6Fy_1/L$ and its displacement is y. For either of the other particles the force is

$$F_2 = (6Fy_2/L) + (3Fy_2/L) = 9Fy_2/L$$

and the displacement is $(y/3) + y_2$. Thus the condition to be satisfied is

$$\frac{9Fy_2}{L\left(\frac{y}{3}+y_2\right)} = \frac{6Fy_1}{Ly} \quad \text{or} \quad \frac{2y_1}{y} = \frac{3y_2}{\frac{y}{3}+y_2}.$$

From Fig. 3, $(y/3) + y_2 = y + y_1$. Thus $y_2 = (2y/3) - y_1$. Hence the condition for the initial displacements becomes

$$2y^2 - 3yy_1 = 2yy_1 - 2y_1^2,$$

which gives $y = 2y_1$. Thus the period of the fundamental as obtained from the formula for simple vibratory motion is

$$P_1 = (2\pi/3)(mL^2/F)^{\frac{1}{2}} = 2.09L(m/F)^{\frac{1}{2}}.$$

Similarly, for the second mode of vibration,

$$P_2 = 1.19L(m/F)^{\frac{1}{2}};$$

and for the third mode of vibration,

$$P_3 = (\pi/3)L(m/F)^{\frac{1}{2}}.$$

Case 4.—The analysis for four particles fortunately is no more complicated than that for three, and an application of the same principles gives for the period of the fundamental,

$$P_1 = 2.05L(F/m)^{\frac{1}{2}}.$$

Having carried these cases through in algebraic detail, we are in position to make the following observations:

1. For a single mass point there is one mode of vibration; for two mass points, two modes; and for three mass points, three modes. In general, the addition of a mass point adds a possible frequency.

2. As might be expected, the more numerous the mass points—and hence the more uniformly the mass is distributed—the more nearly do results obtained by this method agree with those for a uniform string. A point of interest in this connection is that division of the mass into as few as four equal parts gives result for the fundamental which differs by only 2.5 percent from the result for the corresponding uniform string.

The uniform string.—If a string having a uniform distribution of mass is to vibrate in a single loop, each equal portion must experience a restoring force proportional to its displacement. Now the force is proportional to the curvature. Thus we must find a curve in which the curvature is proportional to the displacement. A curve known to satisfy this requirement is the sine curve. Thus if a uniform string is to vibrate as a single loop, it must be dis-

[2] The initial condition described is also sufficient to assure isochronous motions, because, since the acceleration of each particle is proportional to its displacement, in a short interval of time the displacements of all the particles will have decreased by the same fraction of their initial values. Thus, the force on each particle throughout its entire motion is just proportional to its displacement.

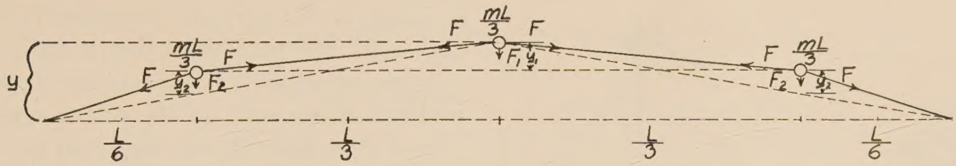

FIG. 3. Case 3.

placed initially into the shape of a sine curve. If the form of the curve be taken as $y=a \sin \pi x/L$, the displacement of the string at its center is a and the curvature at the center is $1/\rho=\pi^2 a/L^2$. Now consider a small length Δx of the string at its center. Its mass is $m\Delta x$ and the restoring force acting on this mass is $\Delta x\cdot(\pi^2 aF/L^2)$. Thus the period as obtained by an application of the formula for simple vibrations is

$$P_1=2\pi(m\Delta xL^2a/\pi^2a\Delta xF)^{\frac{1}{2}}=2L(m/F)^{\frac{1}{2}}.$$

The problems on weighted strings have been presented here as an introduction to the standing vibrations of a continuous string. The problems are important enough, however, to stand on their own merits. Weighted strings are cases of coupled mechanical oscillators and hence the problems growing out of them are fundamental, and their applications numerous indeed. The differential equations describing such problems are of the same form as those for similarly coupled electrical oscillators, and all the conclusions concerning the mechanical oscillators apply equally well to analogous electrical oscillators. This material therefore provides an excellent background for such studies.

A Graphical Method of Measuring Surface Tension and Density

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WHEN a thin-walled glass tube hangs vertically from the arm of a balance with its lower end immersed in a liquid, there is an apparent loss in weight caused by the resultant effect of two forces—an upward force due to buoyancy and a downward force due to the surface tension of the liquid acting around the inner and outer surfaces of the wetted tube. Measurement of this apparent loss in weight for a series of different depths of immersion provides us with a useful method of computing both the coefficient of surface tension σ and density ρ of the liquid. Assuming that the liquid wets the tube (zero angle of contact) and neglecting the buoyancy of the surrounding air, we can express the apparent loss in weight mg as

$$mg=\pi(R_2^2-R_1^2)\rho gh-2\pi\sigma(R_2+R_1), \qquad (1)$$

where h is the depth of immersion of the tube, and R_1 and R_2 are its internal and external radii. Eq. (1) represents a linear relationship between m and h, and provided the dimensions of the tube are such that the buoyancy and surface tension forces are comparable with each other, a plot of m as a function of h should give a straight line with reasonably good intercepts for purposes of interpolation (Fig. 2). The following information can be derived from such a graph:

(a) When m is 0, $h=OA$; hence

$$\sigma=OA\cdot(R_2-R_1)\rho g/2. \qquad (2)$$

This corresponds to the balanced condition as in air and is relevant to the point A on the graph. The coefficient σ is thus expressed in terms of OA, R_2-R_1 and ρ.

(b) When $h=0$, $m=OB$, whereupon

$$\sigma=OB\cdot g/(2\pi(R_2+R_1)); \qquad (3)$$

that is, σ is in terms of OB and R_2+R_1, and is independent of density.

(c) The slope of the graph is $OB/OA=\pi(R_2^2-R_1^2)\rho$, whence

$$\rho=\text{slope}/\pi(R_2^2-R_1^2); \qquad (4)$$

that is, the density of the liquid is obtainable from the slope of the graph and the dimensions of the tube.

(d) The densities and surface tensions of liquids may be compared, provided the same tube is used throughout. Thus for two liquids of densities ρ_1 and ρ_2, and coefficients of surface tension σ_1 and σ_2, $\rho_1/\rho_2=$slope for liquid 1 /slope for liquid $2=(OB/OA)_1/(OB/OA)_2$, and $\sigma_1/\sigma_2=(OB)_1/(OB)_2$. The conditions represented by Eqs. (2) and (3) are thus used to evaluate σ, and that by Eqs. (4), to obtain ρ. It is preferable to use Eq. (3) rather than Eq.

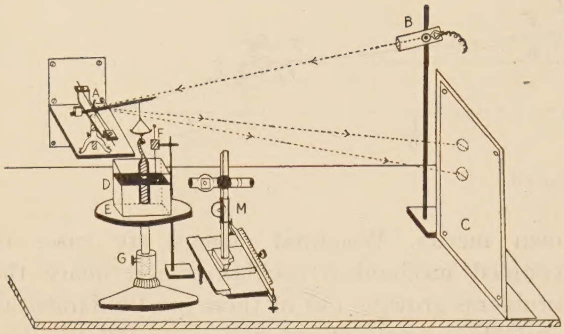

FIG. 1. Diagram of apparatus.

(2) since the percentage error involved in measuring R_2+R_1 instead of R_2-R_1 is much smaller. The deduction of ρ involves the knowledge of R_2-R_1 as well as R_2+R_1, which should be borne in mind when considering the merit of the computed value of ρ. In comparing ρ and σ for different liquids, the accuracy of the results depends only upon the accuracy with which the intercepts and slopes are interpolated from the graphs, since the same tube is employed throughout.

It should be noted that the maximum downward pull on the tube does not occur when $h=0$, but when the tube is just on the point of becoming detached from the liquid raised a distance H above the free surface of the liquid. It is expressible as $2\pi(R_2+R_1)\sigma+\pi(R_2^2-R_1^2)\rho gH$.

Experimental arrangement. A hollow glass tube about 10 cm long and 1 mm wall thickness is drawn out at one end, and attached to the scale pan of a Searle's torsion balance so as to hang vertically (Fig. 1). Both ends of the tube are open, the lower being cut and ground square. By means of a mirror A fixed to the torsion wire, a spot of light from a lamp B is projected on a screen C placed about 3 m from the mirror. Any movement of the balance due to an apparent loss in weight of the partially immersed tube is easily observed. The balance is first equilibrated with the tube suspended in air and the corresponding position of the spot on the screen marked. The tube is then lowered into the liquid by raising the tank D and leveling table E, and after the system has come to rest, the displaced position of the spot of light on the screen is again marked. Provided the angular movement of the torsion wire does not exceed a few degrees we may assume the displacement of the spot of light on the screen to be proportional to the apparent loss in weight of the tube, and so obtain a series of such displacements together with the corresponding depths of immersion. Such depths are measured by the traveling microscope M which is first focused on the lower end of the partially immersed tube, and then on the lower end of the pin F just coincident with the free liquid surface. Calibration of the balance is effected by adding a known small weight (0.50 g) to the scale pan and observing the displacement of the spot of light on the screen.[1]

This method of measuring the apparent loss in weight is applicable only to narrow tubes ($R_2<0.50$ cm), since with wider tubes the angular movements of the torsion wire are much bigger. Proportionality between the displacement of the spot of light on the screen and the apparent loss in weight of the tube cannot then be assumed because of the variation in torque arm with increase in rotation of the wire. We must now adopt a null deflection method in which known weights are added to the scale pan and, for each load, equilibrium of the balance is restored to the same position as that when the tube is suspended in air. This is critically effected by adjusting the depth of immersion of the tube with the thumb screw G until the spot of light is restored to the same position on the screen as for the balanced air condition. The difference between the loads

[1] Champion and Davy, *Properties of Matter*, p. 126; Lecomte Du Nouy, J. Gen. Physiol. 1, 521 (1919).

TABLE I. *Data obtained with glass tubes.*

TUBE 1: $R_1=0.120$ cm; $R_2=0.206$ cm TUBE 2: $R_1=0.259$ cm; $R_2=0.345$ cm

Liquid	Temp. (°C)	Tube	OA (cm)	OB (g)	σ, from OA (dyne/cm)	σ, from OB (dyne/cm)	ρ, from slope (g/cm³)	ρ, from density bottle (g/cm³)	σ_2/σ_1
Water	13.3	1	1.62	0.1487	68.5	σ_2 71.2	1.03(9)	1.00	——
	11.0	2	1.60	0.2740	67.4	71.0	1.04(7)	1.00	——
Chloroform	14.5	1	0.54	0.0715	33.9	σ_1 34.0	1.48(5)	1.48(9)	2.09
	15.0	2	0.54	0.1310	33.8	33.8	1.48(8)	1.48(9)	2.16*

* By capillary tube method.

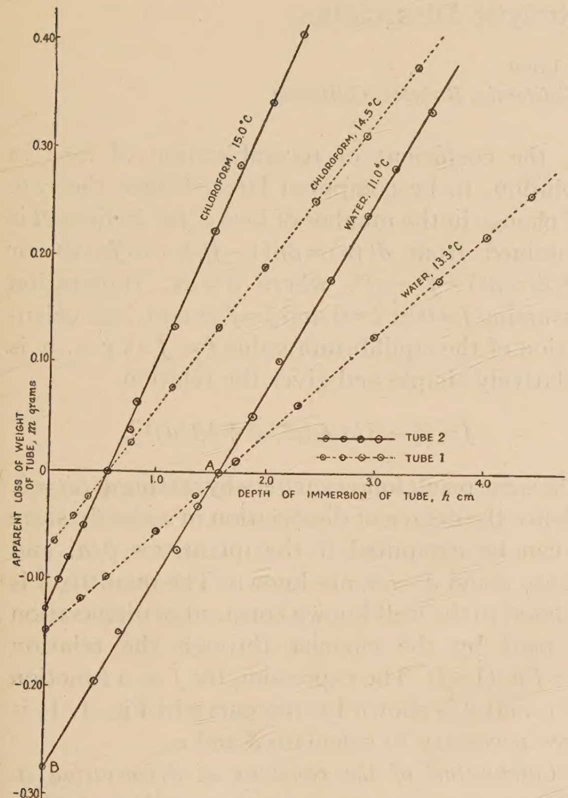

FIG. 2. Plots of m *vs.* h for water and chloroform.

in the pan when the balance is equilibrated initially with the tube suspended in air and when it is partially immersed in the liquid gives the apparent loss in weight.

Specimen results. Results are shown in Fig. 2 for water and chloroform. The linear characteristics of the graphs confirm the validity of the method, especially for liquids that wet glass. The data for σ and ρ appearing in Table I compare favorably with those obtained by other methods. As pointed out earlier, a better value of σ is obtained from the intercept OB than from the intercept OA, and this is substantiated by the results for water. It is not intended that this graphical method will supersede other precision methods of measuring surface tension. The points of interest arising from the analysis certainly suggest that the method is worthy of including in the list of recommended surface tension experiments. Furthermore, this method of utilizing the torsion balance is also to be preferred to the

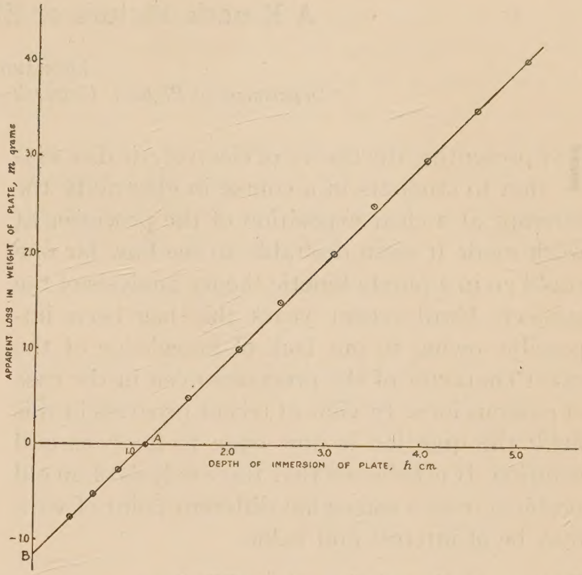

FIG. 3. Plot of m *vs.* h for rectangular plate in water.

ordinary laboratory balance owing to its stability and rapidity in taking up an equilibrium position.

Appendix. If a circular glass rod or a rectangular plate is used instead of the glass tube it is necessary to modify the foregoing expressions as follows:

Circular glass rod of radius R: (a) From intercept $OA(m=0)$, $\sigma=R\rho g\cdot OA/2$; (b) From intercept $OB(h=0)$, $\sigma=OB\cdot g/2\pi R$; gives best value; (c) From slope, $\rho=\text{slope}/\pi R^2$; (d) Comparison of σ and ρ for two liquids in same manner as for the glass-tube method.

Rectangular glass plate of thickness t and breadth b: (a) From intercept $OA\,(m=0)$, $\sigma=bt\rho g\cdot OA/2(b+t)$; for reliable value of σ we must measure t accurately; (b) From intercept $OB(h=0)$, $\sigma=OB\cdot g/2(b+t)$; gives most reliable result since b is much larger than t and can be measured more accurately; (c) From slope, $\rho=\text{slope}/bt$; t must be measured accurately; (d) The comparisons of σ and ρ for two liquids are made in the same manner as with the glass tube.

Typical results for a rectangular glass plate in water at 17.2°C are shown in Fig. 3 and Table II. Again the results are consistent with those obtained by other methods and agree well with the tube results.

TABLE II. *Data obtained with rectangular glass plate in water at 17.2°C.*

BREADTH $b=8.12(7)$ cm, THICKNESS $t=0.12(1)$ cm

OA (cm)	OB (g)	σ, from OA (dyne/cm)	σ, from OB (dyne/cm)	ρ, from slope (g/cm³)
1.150	1.180	67.2	70.2	1.04(3)

A Kinetic Picture of Electrolytic Dissociation

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In presenting the theory of electrolytic dissociation to students in a course in electricity the attempt at a clear exposition of the processes at work made it seem desirable to see how far one could go in a purely kinetic theory analysis of the subject. Until recent years this has been impossible owing to our lack of knowledge of the exact character of the processes even in the case of gaseous ions. In view of recent progress in this field[1] the question is now open to analysis and solution. It is believed that this analysis of an old problem from a somewhat different point of view may be of interest and value.

Degree of dissociation at equilibrium

Assume a molecule AB of some simple electrolyte composed of a positive ion A and a negative ion B. Assume also that from various studies the radius of the molecule AB is known and that the heat of dissociation is known. Let the substance be dissolved so that there are n molecules of AB in a cubic centimeter of the solvent S having a dielectric constant D. Assume, furthermore, that the forces binding A and B are essentially electrical so that the action of the dielectric constant in reducing the energy of the binding can be known. Designate by f the fraction of the molecules dissociated at any time t, with $1-f$ molecules undissociated. Then at time t there will be fn ions of A or B and $(1-f)n$ molecules of AB. Now the ions are produced from AB by impacts of solvent molecules S whose energy at impact exceeds the potential or binding energy of A and B as weakened by the dielectric constant of S. Assume that the production of ions in a time dt is given by $\beta(1-f)ndt$, where β is a constant dependent on the thermal energy of the molecules S, the collision frequency of S on AB, and the potential energy of the binding of A and B, to be evaluated later. The ions are lost in a recombination process to form molecules of AB in the number $\alpha(fn)^2dt$ in a time dt. For recombination depends on the product of the number of A and of B ions per cubic centimeter, $(fn)^2$, and α, the coefficient of recombination of ions in solution, to be computed later. Hence the rate of change in the number of ions $d(fn)$ in time dt is obtained from $d(fn)=\beta n(1-f)dt-\alpha(fn)^2dt$ or $df/dt=\beta(1-f)-af^2$, where $a=\alpha n$. Integration assuming $f=0$ at $t=0$ and $f=f$ at $t=t$, and calculation of the equilibrium value $f\cdot=\bar{f}$ at $t\cdot=.\infty$ is relatively simple and gives the relation

$$\bar{f}=\tfrac{1}{2}[-\beta/a\pm(\beta^2/a^2+4\beta/a)^{\frac{1}{2}}].$$

The same result follows at once by setting $df/dt=0$. Hence the degree of dissociation in a steady state $\bar{f}$ can be computed if the quantities β/a, and hence β and $a=\alpha n$, are known. The quantity $\bar{f}$ is related to the well-known constant of dissociation k used by the chemist through the relation $k=\bar{f}^2n/(1-\bar{f})$. The expression for $\bar{f}$ as a function of a and β is shown by the curve in Fig. 1. It is now necessary to calculate β and α.

Calculation of the constant of dissociation β. The constant β represents the number of "impacts" per second on the molecule whose energy exceeds the dissociation energy W_i in solution. It is given by the number of impacts per second Z of average thermal energy multiplied by F, the ratio of the area under the portion of the energy-distribution curve whose energy exceeds W_i to the total area under the curve. Thus F is at once given from the Maxwell-Boltzmann distribution law by the expression[2]

$$F=\frac{2}{\pi^{\frac{1}{2}}}\int_{W_i/kT}^{\infty}\left(\frac{W}{kT}\right)^{\frac{1}{2}}e^{-W_i/kT}\frac{dW}{kT}.$$

If the forces are purely of the Coulomb type W_i is given by $W_i=e^2/Dr$ for dilute solutions, where r is the ionic separation, if one neglects the difference between the heat of solution of salt and its ions. In general the quantity W_i will be more complicated than this but should be available from thermal data and Born cycles, and will vary with concentration in strong solutions, that is, above 0.01 molar. The quantity W_i must also be corrected for the fact that all the energy of an

[1] L. B. Loeb, *Kinetic Theory of Gases* (McGraw-Hill, ed. 2, 1934), Chap. 11, p. 543.

[2] L. B. Loeb, reference 1, p. 93.

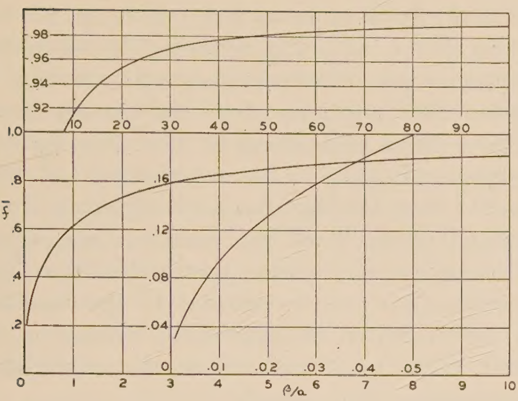

FIG. 1.

impacting molecule of A on a molecule of AB is not available for dissociation as some energy is required to satisfy the laws of momentum and energy exchange on impact.[3] The accuracy of the result will largely depend on a correct choice of the value of energy needed in impact to cause dissociation.

At first sight the collision-frequency Z of the solvent molecules presents an apparently insuperable difficulty since impacts on the surface of the molecule in a liquid cannot be inferred directly from the kinetic theory applicable to gases. It can be shown, however, that the equations resulting from a rigorous procedure are not vastly different from those inferred from simple gas theory. To calculate Z proceed as follows. Consider the fraction of thermal energy present in 1 cm^3 of solvent S that is capable of transmission through the liquid in the form of elastic waves. This will comprise the translational and rotational energies, and the portion of the vibrational energy that is not potential. Designate this fraction by the symbol ϕ. Then the energy in 1 cm^3 of S, or energy density u, is given by $u=\rho C_v\phi T$, where ρ is the density of S, C_v its specific heat at constant volume, and T the absolute temperature. In analogy to the treatment of radiant energy this energy may be thought of as flowing through the liquid as elastic waves with a velocity equal to that of sound in S. It should be noted that in liquids this velocity V_s is greater than the velocity of molecular translation since the free paths are comparable with molecular diameters and the velocity of transmission in a molecule is very high. Hence the energy density is given by $u=\rho C_v\phi T=4\pi K/V_s$, where K is the flux of energy in a particular direction per unit solid angle per second from unit area, and V_s is the velocity of sound in S. If it be assumed that the area of cross section of a molecule of AB of radius R_{AB} is πR^2_{AB}, the energy flux through the molecule is then given by

$$E=\pi K(\pi R^2_{AB})=(\pi V_s\rho\phi C_vT/4\pi)\pi(R_{AB})^2 = (\pi/4)V_s\rho\phi C_vTR^2_{AB}.$$

Now if this flux of energy be divided by the average energy carried by a molecule at T, i.e., by $\phi\rho C_vT/N$, where N is the number of molecules of S per cubic centimeter, one at once evaluates the energy collision-frequency, $Z=(NV_s/4)\pi R^2_{AB}$. This is not unlike the analogous expression for the number of impacts per square centimeter per second on a surface πR^2_{AB} in kinetic theory which reads $Z^1=(N\bar{C}/4)\pi R^2_{AB}$. Thus one has β at once given to the desired degree of approximation by

$$\beta=(\pi/4)FNV_sR^2_{AB}.$$

Calculation of $a=\alpha n$. J. J. Thomson[4, 5] has shown that the coefficient of recombination of gaseous ions is given by the quantity $\alpha=\pi d^2(\bar{C}_A{}^2+\bar{C}_B{}^2)^{\frac{1}{2}}\epsilon$. In this equation it is assumed that the recombining ion moves in a random path at a relative velocity $(\bar{C}_A{}^2+\bar{C}_B{}^2)^{\frac{1}{2}}$, where $\bar{C}_A$ and $\bar{C}_B$ are the average velocities of thermal agitation of the ions A and B. The quantity d is the radius of the sphere of "active attraction;" it is a sphere about an ion of A or B defined by the equation $(3/2)kT=e^2/Dd$. Within the distance d the potential energy of the ions in the medium of dielectric constant D is equal to or greater than the kinetic energy of translation $(3/2)kT$ of the ions, k being the Boltzmann constant. Outside this sphere the ions diffuse apart at a lowered velocity of diffusion if the distance is not much greater than d. Hence it is only when ions are within a distance d of each other that recombination is sure. In gases one must in general use a further factor ϵ which is calculated by the chance that within a distance d of each other a collision with a neutral molecule takes away the excess energy (kinetic energy gained on the last free path before entering d plus

[3] R. N. Varney, Phys. Rev. **47**, 483 (1935); **50**, 159 (1936).

[4] J. J. Thomson, Phil. Mag. **47**, 337 (1934).

[5] L. B. Loeb, reference 1, p. 591ff.

the energy of agitation) so as to reduce the energy within d to less than the potential energy. In view of the high concentration of solvent molecules of the type S in solutions, ϵ is safely taken as 1 even when d is as small as it is in solutions of a high dielectric constant D. This expression is being shown to hold for gaseous ions in this laboratory[6] despite the great difficulty of evaluating the various parameters involved. Its application in solution is hampered somewhat by the difficulty of estimating $\bar{C}_A$ and $\bar{C}_B$ since these depend on the mass of the ion as well as on the temperature. The degree of hydration or solvation of the ions will thus introduce an uncertainty which may alter the mass of the ions in an unknown way. That is, since $\frac{1}{2}m_A C_A^2=(3/2)kT$, $C_A^2=3kT/m_A$ and $\bar{C}_A^2=(8/3\pi)(3kT/m_A)$. Hence for solutions one may write α as

$$\alpha=\pi(\tfrac{2}{3}e^2/D\phi T)^2[(8/\pi)kT(1/m_A+1/m_B)]^{\frac{1}{2}}$$
$$=(8(2\pi)^{\frac{1}{2}}/9)(e^4/D^2)(1/kT)^{\frac{3}{2}}[(1/m_A)+(1/m_B)]^{\frac{1}{2}},$$

where m_A and m_B are the masses of the solvated ions A and B in aqueous solution, or the equivalent in nonaqueous solutions. In assuming the masses of solvated ions care must be taken to be sure that the associated solvent molecules are rigidly bound to the ions A and B; otherwise, in their motions these do not exert a retarding effect in proportion to the number of molecules of solvent assumed bound.[7]

Attention must be called to one more point, namely, that the equation is valid only as long as the ions execute *freely* any type of progressive random motion relative to one another. That is, the paths of the ions need not be straight gaseous free paths but may be as tortuous as one pleases as long as the motion *to sweep out the recombination volume* is a free one progressing randomly. In concentrated solutions where the average proximity of the A and B ions is such that the ions execute oscillations in the neighborhood of each other, it must be clear that a fraction only of the tortuous paths is of the random progressive nature such as to give rise to recombination. The recombination rate is reduced in the measure that the freedom of progressive motion is reduced. With this discussion one may write that the parameter a is given by

$$a=(8/9)(2\pi)^{\frac{1}{2}}(e^4/D^2)(1/kT)^{\frac{3}{2}}(1/m_A+1/m_B)^{\frac{1}{2}}n,$$

and β is given by

$$\beta=(\pi/4)FNV_sR^2{}_{AB}.$$

Application of the theory

A rough comparison can be made as follows for NaCl in H_2O. Assume Na^+ and Cl^- ions separated by a distance $r=2.81\times10^{-8}$ cm, as in a crystal. The *average radius* R_{AB} of the molecule is 2×10^{-8} cm, $D=81$, $N=3.37\times10^{22}$, $m_A=23\times1.65\times10^{-24}$, $m_B=36\times1.65\times10^{-24}$. The fraction of energy available in the impact of an H_2O molecule on NaCl is 59/77; $W_i\times77/59=1.3\times10^{-13}$, $W_i/kT=3.25$. This gives $F=0.076\,2/\sqrt{\pi}=0.0858$. $\beta=6.22\times10^{12}\times0.0858=5.34\times10^{11}$. If the ions are unhydrated, $a=4.56\times10^{-10}n$. If they are hydrated to two molecules apiece, a will roughly be reduced by the factor $1/\sqrt{2}$. Hence β/a for NaCl is $\beta/a=(5.34\times10^{11})/(4.56\times10^{-10}n)=1.17\times10^{21}/n=1.93/M$, where M is the molar concentration; that is, $n=6.06\times10^{20}M$. On this basis one can compute $\bar{f}$ from Fig. 1 and compare it

Table I. *Activity coefficients.*

Molar Conc., M	β/a	$\bar{f}$	Activity Coef.
0.001	—	—	0.967
0.002	—	—	.954
0.005	—	—	.932
0.01	193	—	.909
0.02	96.5	0.99	.880
0.05	38.6	.976	.831
0.1	19.3	.952	.787
0.2	9.65	.92	.740
0.3	6.43	.885	.712
0.5	3.86	.820	.679
0.7	2.79	.783	.659
1.0	1.93	.720	.643
2.0	0.965	.608	.630
3.0	0.643	.545	.657
4.0	0.483	.49	.704

[6] M. E. Gardner, Bull. Am. Phys. Soc. **11**, No. 6, p. 6, abstract 10.

[7] The question of the degree of solvation of ions in solution is an open one. Evidence for solvation comes largely from the data on transport of solvent by ions in fields and from the values of ionic mobilities. It has been shown for gaseous ions (L. B. Loeb, reference 1, p. 570ff.) that complexes such as solvated or hydrated ions in solution are supposed to be, and which are *composed of a relatively large number of solvent molecules, do not exist. Complex ions do exist* in gases that are very similar to those for the same ions in solution. They consist of the electrochemical combinations of a stoichiometrical character comprising of the order of 2 to 4 molecules. The transport phenomena (electrical wind) and reduced mobilities can be ascribed to the polarization of ambient molecules by the ionic charge with consequent transfer of momentum gained from the field without attachment to the ion. There is no reason why conditions in solution should be otherwise. This view as regards the conditions in solution was endorsed in a discussion by Debye as early as 1925.

with the activity coefficient as given by Landolt-Börnstein in Table I.

As is seen at once, while the behavior predicted by the theory shows a trend similar to that shown by NaCl, as well as giving the right order of magnitude, the value of β/α deduced irrespective of n is too large. This might be expected from the nature of the estimate of the value of W_i and is not surprising. A much more serious discrepancy will be brought out in another way and represents the deviations of strong electrolytes in concentrated solution. To illustrate this, one may take the activity coefficient as expressing the value of $\bar{f}$. Then from this one can derive the corresponding value of β/a by the curve of Fig. 1. If the law is correct, since $\beta/a=(\beta/\alpha)(1/n)=H/M$, where H is nearly constant for dilute solutions, then $M(\beta/a)=H$ as derived from the activity coefficient, should be constant. In chloracetic acid, a weak electrolyte at high dilutions, this is seen to be true (Table II). In NaCl the deviations are quite marked. In fact, in an increase in M by 4×10^3, $M(\beta/a)$ increases by a factor of 206. As concentration increases W_i will of course decrease and hence F and also β and H will increase. This increase is *exponential* and becomes important when the ions begin to be separated by less than 10 times the distance 2.8×10^{-8} cm. For NaCl this occurs at $M=0.07$. It is seen that up to $M=0.1$ the increase is steady, $H=(\beta/a)M$ increasing by 10 when it should remain constant. This cannot in great measure be due to the change in β caused by W_i. Above $M=0.2$ the increase in H is clearly exponential and is probably caused by β. Now since a decrease in hydration on increased concentration decreases β/α, the increase in H cannot be due to this cause. The only thing in α affected by concentration is the change produced on the *free* motion of the ion. That is, as the solution gets more concentrated the "progressive recombination path" becomes continually less. Hence, when the concentration increases so that the interionic distances approach on the order of 40 times the normal ionic separation in the molecule ($M\sim0.001$), the ions begin to curtail each other's free progressive motion in the solvent. In this condition the quantity α rapidly decreases and, as is seen, a change from $M=0.001$ to 0.1 produces a reduction in α by a factor of 10. As the solution gets increasingly concentrated its interionic distances approach those in crystals and one has a sort of an ionic "pudding" in which the heat motion of the ions more resembles a vibration than a random motion.

In such a "pudding" in which the ions are the "plums" it is clear that none of the original crystal structure exists. Furthermore, the ions are not in general associated in pairs at 2.8×10^{-8} cm although at any given time some very few are. On the other hand, no ion is independent in its motion. It is at all times under the action of forces of other ions of both signs. The ionic motion is thus a combination of occasional vibrations about positions of minimum potential energy alternating with a progressive random heat motion. In the sense that the greater portion of the ions are not linked in pairs or in a crystal lattice one can speak of a complete dissociation. On the other hand, if complete dissociation means complete independence of each other for the ions of opposite sign, the dissociation is far from complete. Actually it makes no difference what the state is called as long as it is understood. It is believed that the foregoing analysis indicates from another angle what the characteristics of such solutions are.

TABLE II.

MOLAR CONC., M	$\bar{f}$	β/a	$M(\beta/a)=H$
	Chloracetic acid		
0.00005	0.963	25	1.25×10^{-3}
0.0001	.948	18	1.8×10^{-3}
0.00025	.881	6.2	1.55×10^{-3}
0.0005	.806	3.3	1.65×10^{-3}
0.0025	.547	0.66	1.65×10^{-3}
0.005	.423	0.30	1.50×10^{-3}
0.05	.166	0.033	1.65×10^{-3}
	NaCl		
0.001	0.967	28	2.8×10^{-2}
0.002	.954	20	4.0×10^{-2}
0.005	.932	13.3	6.65×10^{-2}
0.01	.909	9.0	9.0×10^{-2}
0.02	.880	6.4	1.28×10^{-1}
0.05	.831	4.05	2.03×10^{-1}
0.1	.787	2.85	2.85×10^{-1}
0.2	.740	2.1	4.2×10^{-1}
0.5	.679	1.47	7.4×10^{-1}
1.0	.643	1.15	1.15
2.0	.630	1.1	2.2
4.0	.704	1.7	6.8

A New Inertia Balance and Operational Definition of Mass

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EVERY student of physical science must secure a thorough understanding of the concept *mass*, which concept includes the two sub-concepts, *inertia* or inertial mass, and *gravitance* or gravitational mass. This inclusion of inertia and gravitance in the single concept, mass, requires the additional knowledge that the ratio of the inertias of two bodies is equal to the ratio of their gravitances, and that to some arbitrarily selected body has been assigned both unit inertia and unit gravitance. Thus the concept of mass involves three fundamental experiments: (1) an operational definition of inertia, (2) an operational definition of gravitance, and (3) the demonstration that the ratio of the inertias of two bodies is equal to the ratio of their gravitances.

In the lecture room and undergraduate laboratory the operational definition of gravitance may be carried out with any balance that is operated by the *weight* of an object, since the strength of the gravitational field of the earth is very approximately constant throughout the volume of an object which can be weighed, and since the centrifugal reaction of an object, due to the spin of the earth, causes the force on it due to gravity to differ from that due to the earth's gravitational field alone, by only 3 parts in 1000, or less. It may be recalled that the force due to gravity decreases only 1 part in 10^7 per foot increase in height, near the surface of the earth.

The operational definition of inertia involves the use of a balance that depends for its operation on the *acceleration* of the body whose inertia is being determined. Since it is assumed that force is to be defined as the product of inertia and acceleration, the inertia determinations must *not* involve measurements of force. Some desirable qualities for an inertia balance which is suitable for use in the lecture room and the undergraduate laboratory are: (1) the force due to gravity should not enter the operation of the balance in any way; (2) the inertia indicated by the balance should be independent of the shape of the body, of the location of the body on the balance, and of the orientation of the body with respect to the balance; (3) it should be possible to measure the inertia of a body quickly; (4), the balance should be substantial and, for the lecture room, generous in size; and (5) the accuracy should be such that the student in the laboratory will feel satisfied with the data obtained.

Figures 1 and 2 illustrate an inertia balance designed by the author that possesses all of these desirable qualities. It is to be noted that the carriage remains parallel to its direction in the rest position, when it is displaced to either side in the horizontal plane in which it is free to vibrate; in this respect it moves like a body suspended by two parallel threads of equal length and swinging in the plane of the threads. The period of the balance is measured with the aid of a watch, preferably a stop-watch.

Operational definition of inertia. Inertia may be defined operationally in the following manner. An arbitrarily chosen body is assigned unit inertia and the period of the balance, with this body on the carriage, is measured. A second body is prepared that causes the balance to have the same period, when it is on the carriage. This second body then has an inertia *equal* to that of the first. In fact, this is *a set* of operations that defines the phrase, "equal inertias." The two bodies, each of unit inertia, are then placed on the carriage together, the period of the balance is

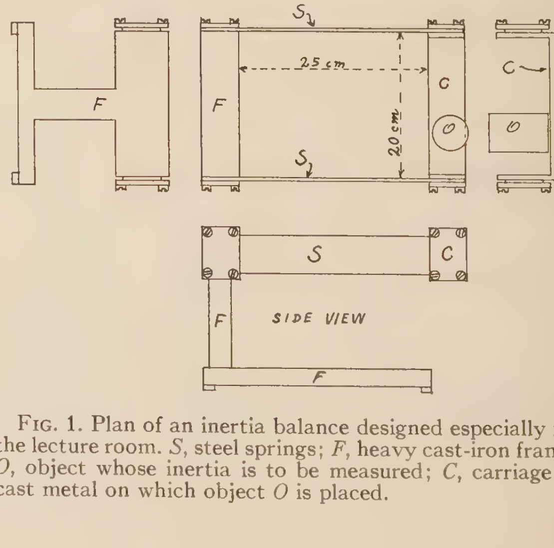

Fig. 1. Plan of an inertia balance designed especially for the lecture room. S, steel springs; F, heavy cast-iron frame; O, object whose inertia is to be measured; C, carriage of cast metal on which object O is placed.

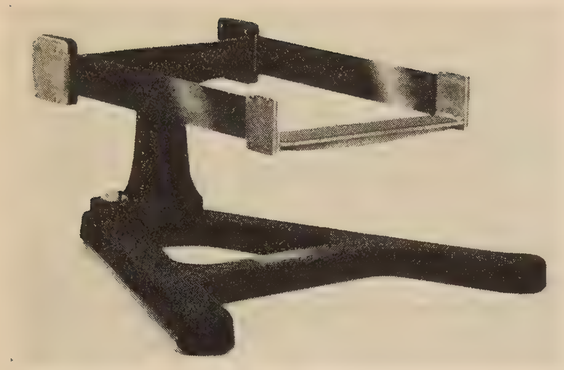

FIG. 2. Photograph of the inertia balance.

determined, and a third body is prepared that causes the same period; *it*, therefore, has 2 units of inertia. By this method a set of, say, five bodies may be prepared, which possess respectively 1, 2, 3, 4 and 5 units of inertia. To determine the unknown inertia of some body, the period of the balance, with this body on the carriage, is substituted in the empirical equation which expresses the inertia on the carriage as a function of the period of the balance; this may be done analytically or graphically. For the balance illustrated in Figs. 1 and 2, the *empirical* relation is of the form,

$$M = aT^2 - b, \tag{1}$$

where M is the inertia on the carriage, T the period of the balance, and a and b are positive constants. It is to be observed that the only qualification required of the balance is that its period always be the same whenever the same body is on the carriage.

To demonstrate the third fundamental experiment mentioned in the first paragraph, it is merely necessary to determine the inertia of each of a set of bodies whose relative gravitances have been determined on some form of balance operated by gravity; an ordinary "set-of-weights" will serve. It will be found that the ratio of the gravitances of any two "weights" is equal to the ratio of their inertias as determined with the inertia balance. Therefore, if unit inertia and unit gravitance are assigned to some one body, then any other body that has M units of gravitance will also have M units of inertia. By international agreement all inertias and gravitances ultimately refer to the body known as the international standard kilogram which is kept in Paris.

Tests of a model of the inertia balance. In Table I, the period T of the balance for each inertia M on the carriage, was calculated from the time required for it to execute 100 double vibrations; the times were measured with a fifth-second stopwatch and ordinary calibrated "weights" were used for the inertias. A least-squares determination of the constants in Eq. (1) yielded $M = 5323T^2 - 575.4$. The mass of the carriage as determined on an ordinary equal-arm laboratory balance was 575 gm. The data show that the greatest deviation of a period from the mean is approximately 0.003 sec.; that the average deviation is only 0.0015 sec.; that half of the deviations are 0.0012 sec. or less; and that the size of the deviation is independent of the magnitude of the inertia. Therefore with this balance one would expect, on the average with a single determination, to have an error of 2.5 percent in measuring a 200-gm load, and an error of 0.86 percent for a 1000-gm load. Thus the balance permits inertia determinations of ample precision for demonstration and laboratory purposes.

To test the effects of the shape and orientation of a body and its position on the carriage, a solid iron bar 1 in. square and $7\frac{3}{16}$ in. long, was timed for 100 double vibrations in each of 4 positions, 6 time measurements being made in each position. A $\frac{5}{32}$-in. slot, milled across the bar halfway between its ends, permitted the bar to be set in a vertical position with the bottom of the carriage in the slot. The following average periods were obtained: bar horizontal and parallel to carriage, 0.5280 sec.; bar horizontal and perpendicular to carriage, 0.5273 sec.; bar vertical, resting on inside edge of carriage, 0.5280 sec.; bar vertical, resting on outside edge of carriage, 0.5286 sec. These data show that the orientation of the body

TABLE I. *A test of the inertia balance with ordinary "weights."*

M (gm)	200	400	600	800	1000
T (sec.)	0.382	0.426	0.468	0.510	0.546
	.386	.430	.468	.508	.544
	.380	.426	.472	.508	.546
	.384	.426	.470	.506	.542
	.384	.430			
		.426			
		.426			
Mean	0.3832	0.4271	0.4695	0.5080	0.5448

and its location on the carriage had an entirely negligible effect on the period. It may be of interest to know that a period of 0.5280 sec. indicates an inertia for the bar of 909 gm, whereas an equal-arm laboratory balance yielded 907 gm.

Periods of the balance with a 1000-gm load, observed with an initial amplitude of several centimeters, and also with a very small amplitude, agreed as closely as the times for 100 double vibrations made with a fifth-second stop-watch. Thus, even extreme variations in the amplitude produced entirely negligible effects on the period.

The sizes of bodies that could be tested conveniently with this model of the inertia balance ranged between 200 and 1000 gm. Loads as great as 2000 gm were carried with safety but the linear relation between the inertia and the square of the period ceased to exist; for example, the indicated inertias were 23 and 91 gm too large at 1200- and 1600-gm loads respectively. Undoubtedly a slight buckling of the springs took place at loads in excess of about 1100 gm.

It is to be observed that a discussion of harmonic motion is *not* necessary, or even desirable, in demonstrating the inertia balance to an elementary class. It can be seen by the students that the change in period of the balance is *not* dependent on gravity, and the students have had sufficient qualitative experience with starting, stopping and shaking objects to expect that a change in the inertia of the body on the balance will cause a change in its period, inertia initially being defined qualitatively in terms of their experience.

An increase in the accuracy of data obtained with the balance may be desirable in an advanced laboratory. The precision may be increased by timing the balance over longer time intervals, or by using a continuously moving chronograph or electric stop-clock.

The inertia of a volume of liquid may be measured with the balance if the liquid is enclosed in a bottle which is filled up to the neck. A container of shot or sand may have its inertia determined without the use of any special precautions.

Accessories and additional experiments. Two accessories to the inertia balance make possible several additional laboratory experiments. With a good micrometer screw attached to the frame of the balance the static deflection of the carriage may be measured. Three metal blocks permit the tilting of the balance in such a way that the carriage moves in a plane which makes an angle of about seven degrees with the horizontal. If a load is put on the carriage when the balance is in the tilted position, the force due to gravity on the load will cause the carriage to assume a deflected position, and the magnitude of the deflection caused by the load may be measured with the micrometer screw. The tilted balance thus serves as a spring balance operated by gravity, and with it an operational definition of gravitance may be carried out in a manner exactly similar to that described for the operational definition of inertia.

During the preparation of a set of, say, five bodies having gravitances of 1, 2, 3, 4 and 5 units, it will be found that the deflection of the balance is directly proportional to the load. This shows that the deflection of the carriage is directly proportional to the force (Hooke's law), and that it should execute harmonic motion when it vibrates. When the balance was used as an inertia balance, it was observed that the period was independent of the amplitude, and that the square of the period was proportional to the mass of the carriage and load. These two facts demonstrate that the carriage does execute harmonic motion.

The set of bodies having inertias of 1, 2, 3, 4 and 5 units may now have their gravitances determined by measuring the deflections which they cause on the tilted balance. It will be found that the ratios of their gravitances are equal respectively to the ratios of their inertias.

The strength of gravity g may be determined with the balance. Since the carriage executes harmonic motion its period will be given by

$$T^2=(4\pi^2 d/F)(M+m), \tag{2}$$

where m and M are respectively the inertias of the carriage and the load, and F is the force causing the deflection d of the carriage (force parallel to deflection). If g is defined such that the *weight* of a body having a gravitance M_0 is $M_0 g$, and if unit inertia and unit gravitance are assigned to some one object, we may write

$$(M_0 g \sin\theta)/d=(4\pi^2/T^2)(M+m), \tag{3}$$

from which g may be calculated; θ is the angle of tilt of the carriage. In a test d was 0.577 cm for a load of 1000 gm when $\sin\theta$ was 0.1239. From the inertia balance experiments it is seen that $(M+m)/T^2=5223$ gm/sec.^{2}. These data lead to a

TABLE II. *Dependence of stiffness of springs on length.*

Set	L (cm)	T^2 (sec.^{2})	Combination	$(T_1/T_2)^2$	$(L_1/L_2)^3$
a	22.5	0.1753	c & b	1.213	1.215
b	24.0	0.2125	c & a	1.471	1.471
c	25.6	0.2580	b & a	1.212	1.214

value of 976.7 dynes/gm for g. Here the strength of gravity has been measured in *dynamical* units of force per unit of mass.

The dependence of the stiffness of the springs on their length may be demonstrated. Eq. (2) shows that the force per unit of displacement for constant load is inversely proportional to the square of the period. The data in Table II show, therefore, that the force per unit displacement is inversely proportional to the cube of the length of the springs.

No doubt other uses for this inertia balance will be found. For example, a few metal or wood balls and some thread make possible the demonstration of forced vibrations with and without resonance, interaction of coupled systems, and resonance of a coupled system.

An Experiment on Variable, Linear Flow of Heat

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A QUESTION often raised by "visually minded" students taking theoretical courses in physics is, "Will values obtained from the derived equations agree with experimental data?" Because of certain assumptions made and the seemingly unnatural boundary conditions sometimes assumed in deriving the equations, there is little wonder that such questions should arise, not so much concerning the correctness of the equations as the degree of precision with which the calculated values agree with those experimentally obtained. The following problem in heat flow, the experimental technic of which seems not to have been described in the literature, lends itself very satisfactorily both to experimental and to theoretical treatment, and serves admirably the purpose of giving the student a feeling of confidence in, and familiarity with, the Fourier method of treating such problems. The problem may be stated as follows:

> If one end of a long, thin iron bar, suspended in open air, were suddenly raised to and maintained at a constant temperature of approximately 100°C, how would temperatures at various points along the bar, measured as a function of time, compare with theoretically computed values?

The theoretical solution of this problem is obtained by solving the well-known equation for the flow of heat along a thin bar radiating freely into a medium with a constant temperature. In this equation,

$$\partial\theta/\partial t=(k/c\rho)(\partial^2\theta/\partial x^2)-(HP/c\rho S)\theta, \qquad (1)$$

θ is the temperature at time t, at any point located a distance x from the heated end of the bar; k is the thermal conductivity; c, the specific heat; ρ, the density; H, the emissivity; P, the perimeter of the bar; and S, the area of the cross section of the bar. In the theoretical treatment, the bar is assumed to be infinitely long.

The boundary conditions to be satisfied are: (1) at $x=0$, $\theta=\theta_1$, at all times; (2) at $x=\infty$, $\theta=\theta_0$, at all times; (3) at $t=0$, $\theta=\theta_0$, throughout the bar. For convenience in developing the theoretical equations, θ_0 is taken equal to zero and all other temperatures are measured in degrees centigrade above θ_0.

By following the method presented by Fourier,[1] making the proper substitutions and integrating between the proper limits, the foregoing conditions may be satisfied and the following working equation obtained:

$$\theta=\theta_1 e^{-(HP/kS)^{\frac{1}{2}}x}+\theta_1 e^{(HP/kS)^{\frac{1}{2}}x}\psi\left[\left(\frac{HPt}{c\rho S}\right)^{\frac{1}{2}}+\frac{x}{2(kt/c\rho)^{\frac{1}{2}}}\right]$$
$$-\theta_1 e^{-(HP/kS)^{\frac{1}{2}}x}\psi\left[\left(\frac{HPt}{c\rho S}\right)^{\frac{1}{2}}-\frac{x}{2(kt/c\rho)^{\frac{1}{2}}}\right], \qquad (2)$$

where $$\psi(R)=\frac{1}{\pi^{\frac{1}{2}}}\int_{r=R}^{r=\infty}e^{-r^2dr}$$

[1] *The Analytical Theory of Heat* (Cambridge Univ. Press, 1878), pp. 352–59.

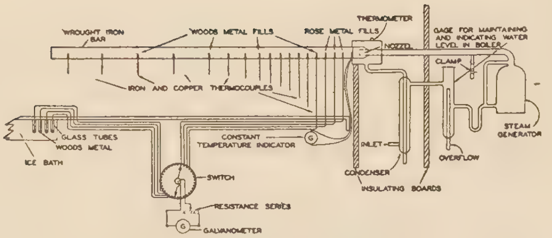

FIG. 1. Diagram of the Apparatus.

is the usual probability integral, R in the second term is taken as $(HPt/c\rho S)^{\frac{1}{2}}+x/2(kt/c\rho)^{\frac{1}{2}}$, and R in the third term is taken as $(HPt/c\rho S)^{\frac{1}{2}}-x/2(kt/c\rho)^{\frac{1}{2}}$. From Eq. (2) values of θ can be readily computed because the value of the probability integral can be obtained from tables.[2]

The constants of the theoretical equation were determined from the 1-in. diameter, polished wrought iron bar which was used in securing the experimental data. The quantities S and P were measured; c and ρ were determined by the usual methods; H was calculated from the equation $H=H_N c\rho S/P$, in which H_N had been determined by applying Newton's law of cooling, $\partial\theta/\partial t=H_N(\theta-\theta_0)$, to a cooling curve obtained experimentally from a piece of the bar; k was calculated from the equation $\theta=\theta_1 e^{-(HP/kS)^{\frac{1}{2}}x}$, which represents the steady state of the bar when $t=\infty$. The constant temperature θ_1 chosen for the hot end of the bar was that of steam. With room temperature used as the zero of the surrounding medium, calculations showed that when $t=\infty$ the temperature of the bar 1 m from the hot end would be approximately 1°C above room temperature and at 2 m, less than 0.01°C. This represented a rise in temperature well below the limit of experimental error and indicated, therefore, that a section of the bar 2 m or more in length could be considered as being infinite in length.

In the apparatus for obtaining the data (Fig. 1), a 7-ft. length of the bar was used and the temperatures at 17 points along it were read at various times by means of thermocouples made from No. 26 B. & S. gage copper and iron wire, placed in small holes drilled to the center of the bar. Good thermal contact was obtained by insulating the wires except at the junction and filling the holes in the bar with Wood's metal along the cooler part of the bar, and with Rose's metal near the hot end. The cold junctions were imbedded in Wood's metal in small individual test tubes and immersed in an ice bath. Each thermocouple was complete in itself and used no part of the bar in its circuit. A switching arrangement made it possible to read the temperature at any one of the 17 points, at any time, by means of a wall galvanometer. The cooling effect on the bar caused by the thermocouples was reduced to a minimum by using small wire and keeping the circuits open except when readings were being made.

The boundary conditions of the theoretical equation were met and kept constant: (1) by having the bar long enough so that its cool end did not change in temperature by a readable amount, (2) by supporting the bar only at its ends, (3) by locating the bar 2 ft. or more from any surrounding objects in order to allow the free circulation of air around it, (4) by drawing the warm air out of the room with a fan placed near the ceiling and allowing the cool air from the hallway to enter at a rate such that the temperature of the air surrounding the bar was constant, (5) by using a rapid, constant flow of steam for heating the end of the bar, projecting the steam through a specially constructed nozzle and heating unit designed to heat the entire surface of the end of the bar uniformly and rapidly (Fig. 2), and (6) by placing all warm objects at a considerable distance from the bar and insulating them to prevent the transfer of heat to the bar by radiation. The arrangement for maintaining the end of the bar at constant temperature consisted of an insulated metal can 2.5 in. in diameter and 3.5 in. long attached steam-tight to the end of the bar by a press-fit

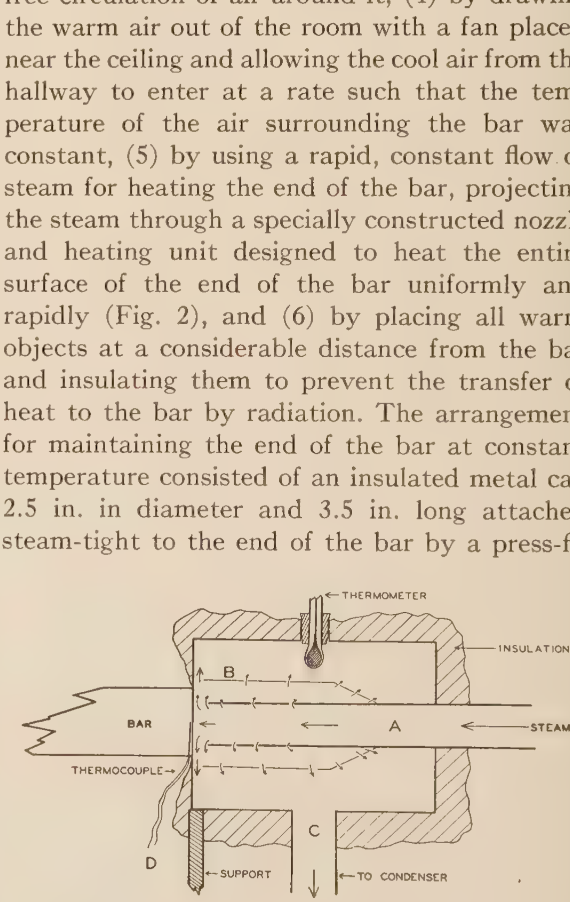

FIG. 2. Steam nozzle for heating the end of the bar.

[2] Such as B. O. Peirce, *A Short Table of Integrals* (Ginn, 1910), pp. 116–20.

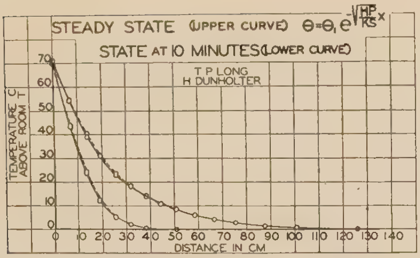

FIG. 3. Graph of temperature *vs.* distance from hot end of bar. (Experimental——; calculated . . . . .).

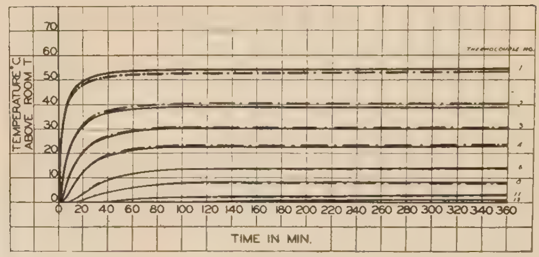

FIG. 4. Graph of temperature *vs.* time. (Experimental——; calculated—— – ——).

hole in the end of the can. The end of the bar was flush with the inside surface of the can. A $\frac{5}{8}$-in. metal nozzle (*A*, Fig. 2) extended through the end opposite the bar and to within $\frac{1}{4}$-in. of the bar. Concentric with the nozzle was a baffle *B*, $1\frac{1}{4}$-in. in diameter, attached to the can at the bar end, and extending to the middle of the can. Small holes were made in the baffle and in the nozzle near its end for the purpose of distributing the steam evenly over the end of the bar and preventing condensed steam from striking the bar. The steam outlet, near the center of the bottom side of the can, was attached to a condenser to eliminate back pressure. A thermocouple *C*, made of No. 36 B. & S. gage copper and iron wire, was placed 0.01 in. beneath the end of the bar; it was attached permanently to a wall galvanometer, and used to determine the rapidity of rise in temperature when the steam was applied and the constancy of the temperature during the experiment. The temperature rose to within 0.1°C of the maximum in 4 sec. and remained constant within 0.06°C.

The data were collected over a period of 6 hr. at the end of which time the steady state had practically been reached; during the last two hours no thermocouple showed a change as great as 0.1°C. Theoretical temperatures were calculated for each position on the bar occupied by a thermocouple, at 8 time-intervals ranging from 5 min. to 6 hr., and also at infinite time.

As a means of comparison the experimental and theoretical data were plotted on the same graph sheets. For simplicity of illustration, only a few curves are shown both in Fig. 3 and Fig. 4. Any other curves that might have been chosen would have shown as close an agreement between experimental and theoretical values. In Fig. 3, the upper curves are plotted from experimental data taken at the end of 6 hr. (approximately steady state) and theoretical data at infinite time, the steady state. Fig. 4 shows the temperature as a function of time for 8 of the 17 points on the bar at which readings were made. At some points the experimental temperature values were slightly higher than the theoretical while at others they were slightly lower. Experimental and theoretical values agreed to within 3 percent for the greatest difference and had an average agreement considerably better than this. The nature of the variations between the values indicate an uneven composition of the bar rather than anything inherently wrong with the experimental method.

The theoretical work involved is an excellent example of Fourier analysis. The apparatus required is to be found in almost any laboratory and the agreement between theory and experiment is sufficiently close to give the student a feeling of confidence in the theoretical method employed. The apparatus can be set up permanently and, with the constants given, students in an advanced course in heat should be able to obtain the necessary data and make the computations in a relatively short time.

In these days, a man who says that a thing cannot be done is quite apt to be interrupted by some idiot doing it.—ELBERT HUBBARD

The Stroboscopic Ripple Tank as a Teaching Aid

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A STROBOSCOPIC ripple tank is a convenient and useful apparatus with which to demonstrate both the properties of ripples on the surfaces of liquids and the properties of sound, light and radio waves. It may be that teachers have recognized its possibilities but that the expense of such apparatus, or the time required to build it, has prevented many from enjoying its use. It is to the many departments that lack adequate budgets or well-equipped machine shops that I am addressing these remarks. The job of building the apparatus could well be made a project for those students who are particularly interested in apparatus and like to build devices if for no other reason than to see them work.

A great many devices have been used for the purpose of producing ripples on the surfaces of liquids in small tanks. A stylus attached to one prong of a tuning fork and dipped into the liquid was one of the early methods,[1] and is still in use. Another method employs tiny puffs of air from small nozzles connected to a bicycle pump and supported just above the surface of the liquid.[2] V. E. Eaton[3] produces ripples by means of a wire dipped into water and vibrated electromagnetically; the wire carries 60-cycle current and passes between the poles of a permanent magnet.

The ripple tank to be described (Fig. 1) is similar to Professor Eaton's but instead of being made by a skilled machinist was made largely from pick-up parts collected in a small junior college laboratory. The small table upon which it is built is 15 in. high and the dimensions of the top are about 14×20 in. The tank itself is 11×14 in. and about 1 in. deep. It was made by cutting a hole in the top of the table and fitting it with a glass bottom. The glass is set in white lead and is supported by cleats nailed on the underneath side of the table around the edges of the hole. The vibrating wire *WW* is fastened to the free ends of two strap hinges. One of the hinges has one end

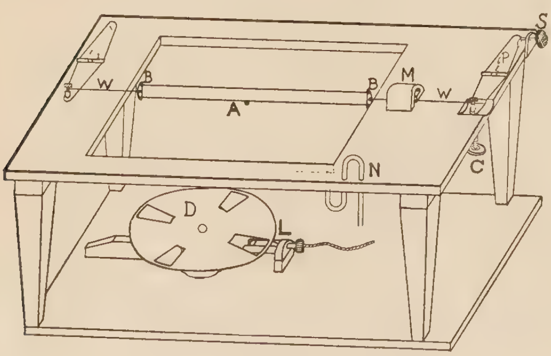

Fig. 1. The stroboscopic ripple tank.

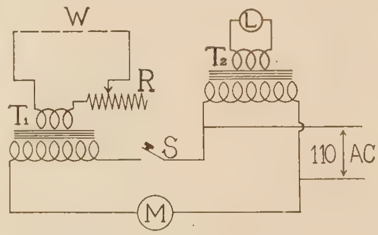

Fig. 2. Wiring diagram.

rigidly screwed to the table top and the other hinge is mounted with a single screw *P* so that it can rotate in a horizontal plane. This feature is desirable so that the force in the wire can be adjusted with the thumb screw *S*. Vertical adjustments in the wire can be made by means of the screw *C*. The permanent magnet *M* is part of a discarded watt-hour meter. A siphon *N* is used to drain the tank. Two small aluminum brackets *BB* are used to offset the wire so that it will reach the water in the tank. A small lead shot *A* attached to the wire barely dips into the water and serves as a source of circular waves. When plane waves are desired the wire is loosened at the binding posts on the hinges and the brackets *BB* are turned over so that the top wire touches the water along its length. The stroboscope disk and motor are at *D*. The light source is at *L*.

The stroboscope motor operates on 110 a.c. and is part of an old electric fan. Its speed is controlled[4] by a rheostat *R*, Fig. 2. Current from

[1] Rayleigh, *Scientific Papers*, Vol. 3, p. 382.
[2] W. Baldwin, Jr., R. S. I. 1, 309 (1930). Good bibliographies on the subject of water ripples will be found in this article and in one by R. C. Brown, Proc. Phys. Soc. 48, 312 (1936).
[3] *A Laboratory Course in College Physics* (Edwards Bro., 1936), p. 29–32.

[4] A small synchronous motor would be advantageous for most ripple tank work because it eliminates keeping the stroboscope disk under control with a rheostat. The small

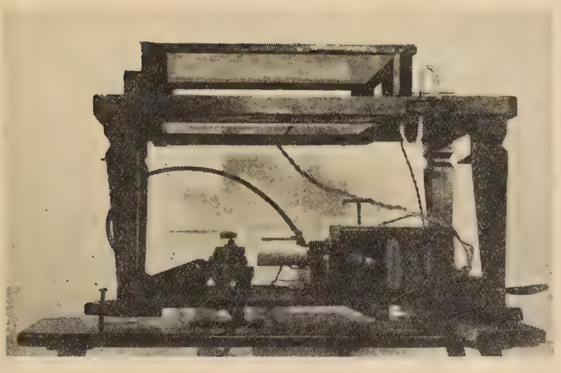

FIG. 3. The ripple tank showing the position of the viewing screen when in use; T is the transformer unit shown at T_1 in Fig. 2.

the secondary of the transformer T_1 passes through the vibrating wire W. The source of illumination now in use is a small concentrated filament lamp of the type used as an exciter lamp in a sound motion picture projector. It operates from the secondary of a bell transformer T_2. A suitably mounted automobile head lamp[5] also works very well as a source of illumination. In Fig. 2, L is the light source, M is the stroboscope motor, and S is a switch. Modifications can of course be made in this scheme to suit the parts and materials one happens to have available.

The ripples are viewed on a screen made of tracing cloth, ground glass or translucent paper mounted on a frame placed on the top of the table as shown in Fig. 3. If one wishes to make photographic prints of the patterns formed by the ripples the translucent screen is replaced by a glass screen and the paper exposed by placing it face downward on the glass. Figs. 4 to 10 were made in this manner. The ripples act as lenses in focusing the light from below. In Fig. 5 the line AB marks the edge of a plate of glass placed just beneath the surface of the water and tilted upward from the bottom of the tank so that the depth of the water varies from a maximum at the right to a minimum at the line AB. The print

adjustments necessary in R do not affect the amplitude of the ripples appreciably. The arrangement shown in Fig. 2 is used for convenience because the rheostat R is built into the transformer unit. With 60-cycle current in the vibrating wire and 4 apertures in the stroboscope disk, a motor speed of 900 rev./min. is required.

[5] The photocell exciter lamp furnishes a line source and is used in studying plane waves. The automobile head lamp is superior for studying circular waves. If a single-contact head lamp bulb is used the two types of lamps can be readily interchanged.

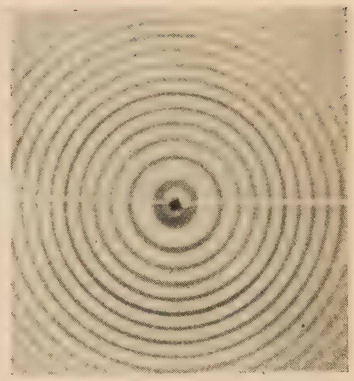

FIG. 4. Simple circular waves radiating from a single point source.

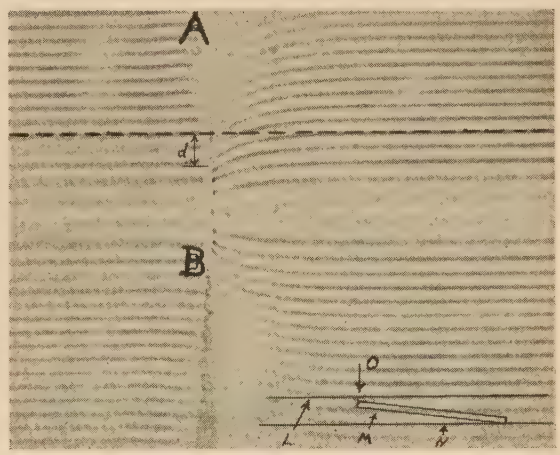

FIG. 5. Variation in the velocity of the ripples with the depth of water. In the diagram at the right, L indicates the surface of the water, M a glass plate, N the bottom of the tank, and O the line in the surface of the water indicated by the line AB in the print. The distance d indicates the approximate amount of bending that has occurred in the ripple in passing from the source out to the position indicated by the dotted line. The waves in the center have a different appearance from those at the top and bottom because of the curvature of the liquid surface where the wire touches the water.

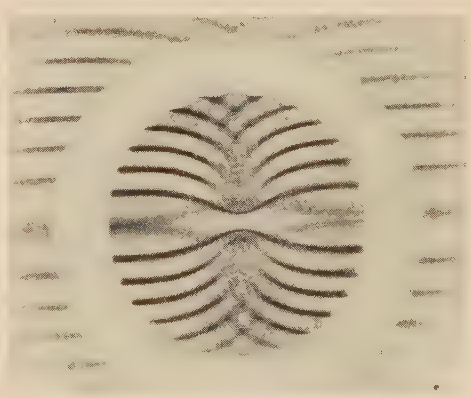

FIG. 6. Variation in the velocity of the ripples brought about by placing a lens directly beneath the source of plane waves.

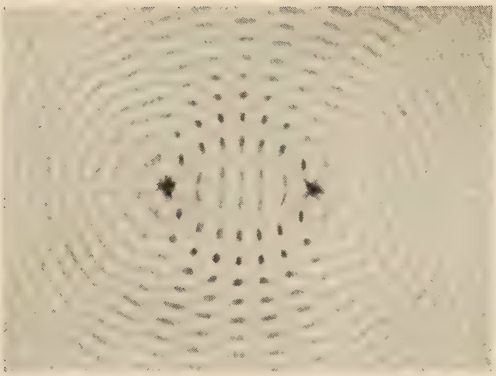

FIG. 7. Interference pattern formed by two point sources radiating circular waves.

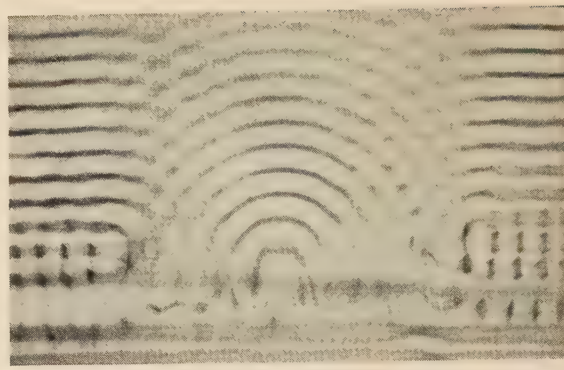

FIG. 9. Pattern formed when plane waves strike an obstacle containing a narrow vertical slit at normal incidence. Huygen's principle appears to be illustrated. Careful inspection shows the diffraction of the waves as they pass by the edges of the obstacle.

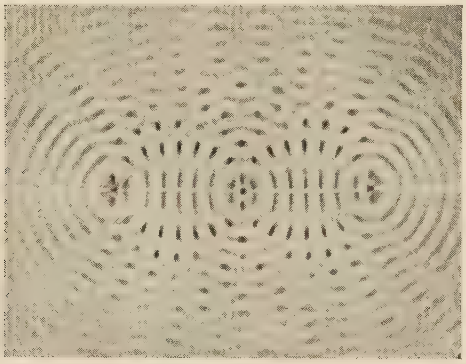

FIG. 8. Interference of three point sources.

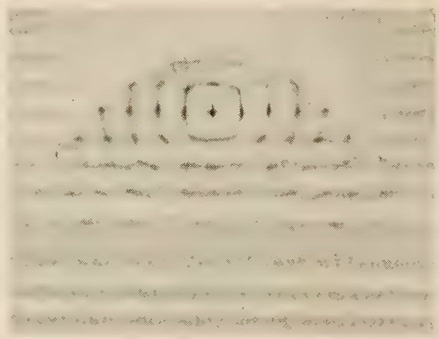

FIG. 10. Reflection of plane waves from a parabolic reflector. Circular waves may be reflected by placing their source at the principle focus of the reflector.

shows that the speed of the ripples is less in shallow than in deep water; the distance traveled by the ripples during the time between successive flashes of light from the stroboscope disk is less in the shallow water as shown by the curvature of the ripples. This effect is further illustrated in Fig. 6 by placing a plano-convex lens in the bottom of the tank so that the top of it is just beneath the surface of the water. The source of plane waves is directly above the center of the lens.

The prints illustrate the extreme flexibility of the ripple tank as a device for purposes of demonstration. It lends itself readily in showing the properties of wave motion as they are encountered in three important branches of general physics and for this reason alone is invaluable as a teaching aid. If classes are small the small viewing screen on the top of the tank will suffice for demonstrations. For larger classes it may be necessary to project the wave patterns on a larger screen, in which case a stronger source of illumination and an ordinary mirror mounted over the top of the tank may be employed. If one is interested in making quantitative measurements of the water-wave speeds or of surface tension, the frequency of vibration of the ripples also must be determined.

"What is the use of this new invention?" someone asked Franklin. "What is the use of a new-born child?" was his reply.—*Memoirs of Baron de Grimm.*

An Optical Experiment for the Elementary Laboratory

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IN the average laboratory, the application of the optical pyrometer as an adjunct to elementary experiments is frequently overlooked. There are, however, numerous instances in which this important instrument can be used to advantage. In this category belong studies of luminous sources, from which the following experiment is selected.

With the usual type of photometer, it is necessary to have one source of known candlepower. Usually a convenient source is arbitrarily assigned a definite value and so given to the student. The author accidentally discovered a means of dispensing with the "standard" source, which at the same time retains the essential features of the illumination measurement.

It has been found possible to use a footcandle meter employing a dry-disk type of photoelectric cell as a means of measuring approximately the candlepower of a luminous source. If the light from the source strikes the cell at normal incidence and the distance of the source from the cell is measured, the candlepower of the source may be computed with the help of the illumination equation, $L=C/d^2$, where L is the illumination in footcandles, C is the candlepower of the source in the direction selected, and d is the distance between source and cell in feet. The application of the footcandle meter in this capacity is not to be considered a precision measurement, although, if desired, the meter may be recalibrated frequently with the aid of standard sources, thus affording more exact measurements than if the calibration is assumed to remain stable. Another feature which cannot be disregarded in precision work arises from the difference in color of various sources. It is hardly necessary to indicate the corrections to be made, since the character of the experiment precludes the use of extreme precision.

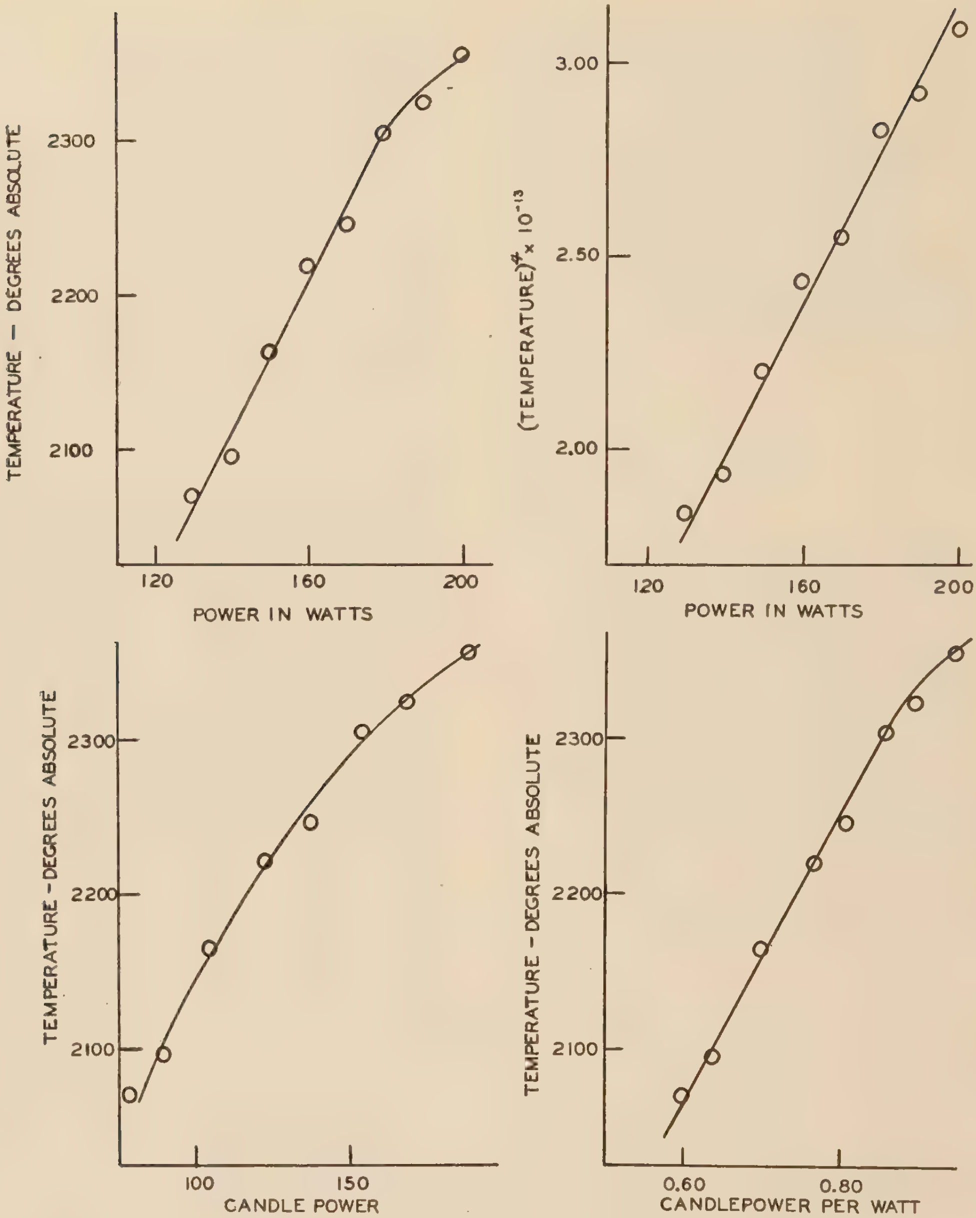
In practice an incandescent lamp of the Mazda type with clear-glass bulb is mounted so that the center of the bulb is 1 ft. from the photoelectric cell. The lamp is so adjusted that the center of the semicircular filament is in line with the center of the photoelectric cell. With the aid of a rheostat, the power input P to the lamp may be varied, a watt-meter serving to indicate the power at any particular setting of the rheostat. For each setting of the rheostat, the illumination in footcandles is read on the meter, and at the same time the temperature T of the filament is obtained with the optical pyrometer. The candlepower C of the lamp is then computed, and the temperature reading corrected for the emissivity of tungsten. Table I gives the results of a typical experiment, while Figs. 1–4 illustrate some of the ways in which the data may be plotted.

Table I. *Results of a typical experiment.*

Power Input, P (w)	Obs. Temp., T°A	T, Corrected for Emissivity	T^4 ($\times 10^{13}$)	Candlepower, C	C/P
130	1926	2070	1.837	78.0	0.60
140	1949	2097	1.935	90.0	.64
150	2009	2165	2.201	105	.70
160	2056	2221	2.434	123	.77
170	2078	2247	2.550	138	.81
180	2128	2306	2.827	155	.86
190	2144	2325	2.920	170	.90
200	2172	2357	3.088	190	.95

It will be found necessary to make several observations with the optical pyrometer for each temperature measurement. With the 200-watt lamp employed, it was found possible to obtain close agreement among five consecutive settings on the lamp filament.

It should be emphasized that the experiment as described is by no means a precision one. As outlined, the illumination from the source is measured in one direction only from the lamp. If desired, the mean horizontal candlepower could be determined for each value of the power input, though this might well form the basis for a later experiment. The lack of stability of the dry-disk type of footcandle meter will also



Figs. 1–4. Illustrating some ways of plotting the data.

introduce errors of appreciable magnitude. It is believed, however, that the student's mind will be more at ease if the candlepower of the source is approximately measured than if an arbitrary value is given to the "standard" source used with the ordinary Bunsen photometer.

Truth comes out of error more easily than out of confusion.—Francis Bacon

A Double Oscilloscope

William Hurst
Duke University, Durham, North Carolina

The writer has recently had occasion to construct and adjust a Matthew's oscillograph with associated amplifying apparatus to be used for the measurement of nerve impulses. It appeared that one source of inconvenience in the use of an instrument of this kind is the pick-up of 60-cycle interference from overhead lights and other laboratory disturbances. While the trouble in this instance was eliminated by shielding of the room, it appeared worth while to develop a double oscilloscope since it would make possible the elimination of undesirable frequencies. It was planned to balance out the effect of such undesirable frequencies by feeding it into the two moving elements of the double oscilloscope. The motion of a beam of light reflected in turn from mirrors attached to each oscilloscope would correspond to the desired wave form fed into only one of the oscilloscopes.

The instrument to be described represents a stage in the development of such an instrument. In its present form it may be used to demonstrate to a large audience some of the important principles of wave form analysis. In order that the wave pattern be visible from a considerable distance it was necessary to construct certain parts (mirrors, etc.) on a larger scale than would be necessary for work with photographic recording. This fact limits the frequency response of the present instrument. There seems to be no reason why the frequency response can not be pushed up to 8,000 cycles/sec. with properly designed moving parts.

This work has also led to the development of a mechanical sweep (for time-axis) which in addition to being essential to visual demonstrations, can also be applied to the study and demonstration of sound waves. In such a case it would replace the octagon faced mirror sometimes used for such purposes.

The Oscilloscope. The essential parts of the oscilloscope are shown in Fig. 1. The shaded portion represents soft annealed iron. The field coils A and A_1 were wound with No. 18 D.C.C. wire, each coil having a resistance of $\frac{1}{4}$ ohm. They were connected in series for operation from a 3-v source. The moving elements of the oscilloscope, shown at C and C_1, consist of one turn of copper ribbon, 0.012×0.125 in. Care must be exercised to make these elements in the form of perfect circles in order to obtain the benefit of as small an air gap as possible in the magnetic circuit. If the copper is annealed just before bending no great amount of trouble will be experienced. It is well to make the elements first and then machine and fit the iron pole pieces later. The iron framework was made from $\frac{1}{4}\times2$-in. rectangular stock, machined and drilled, and then annealed. The moving elements are suspended by the leads D and D_1 which are rolled down to have the same thickness, 0.012 in. They are cut to 0.125 in. width and left hard. The rolling gives them better spring characteristics. The mirrors B and B_1 are mounted on supports of brass, $\frac{3}{8}\times\frac{7}{8}\times0.010$ in., which are hinged with phosphor bronze straight springs measuring in cross section 0.005×0.030 in. Two springs are required for each support. The moving elements actuate the mirrors by means of hard, brass wire connecting rods, 0.020 in. in diameter. These connecting rods are fastened to the mirror supports with phosphor

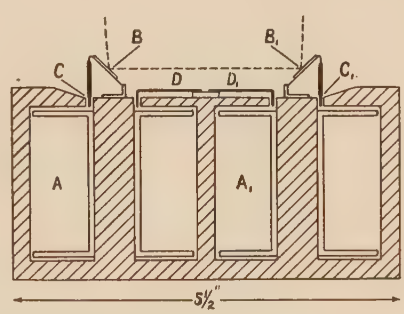


Fig. 1. Cross section of double oscilloscope.

bronze springs of the same cross section as those used to hinge the mirror supports. The effective length of each of these springs is $\frac{3}{16}$ in. The mirrors should be examined just after cementing to make certain that they are flat. If they are not plane, the mirrors can be removed before the cement has set hard. For cement, celluloid dissolved in amyl acetate was used as a matter of

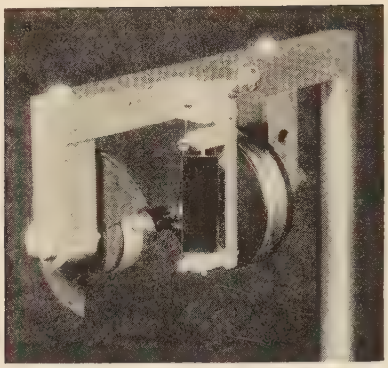


FIG. 2. Photograph of mechanical sweep.

convenience. No doubt there are many cements on the market which are as good or better. A slight amount of distortion may be removed by rotating the lens used to focus the light source reflected by the mirrors onto the screen. The two oscilloscopes are fed with separate one-tube (6C5) stages of amplification, each with a volume control and a variable grid bias of 0 to 1000 ohms. For best results the secondary of an impedance transformer should be removed and the proper value of impedance determined by trial, although an impedance matching transformer with value of about 0.15 ohm at 600 cycles/sec. will work fairly well. Care should be observed in the construction of the moving elements for they must have equal periods and equal mass distribution. The springs must have equal restoring force and the damping effect on the coils must be the same. The damping effect may be controlled by shunting the field of the over-damped coil. Few corrections will be found necessary if the parts are well made in duplicate. When complete, the double oscilloscope needs a final correction for period. This adjustment can be made by snapping both mirrors at the same time and watching for beat notes on the projected image. If the periods are unequal, the mirrors may be snapped individually with a mechanical light-sweep throwing the image across the screen, and the relative frequency observed by a shift in either direction. It is possible in this way to ascertain which unit is in need of extra mass. A drop of soft wax melted on the connecting rod made an ideal medium of fine adjustment. The wax was applied by means of a hot wire until the unit was over weighted. The final adjustment was accomplished by removing thin slivers of the wax with a razor blade.

The Mechanical Sweep. To make the oscilloscope applicable to certain forms of demonstration work, a mechanical sweep (Figs. 2 and 3) was devised to project the image with a time-axis on a large screen. It consists of a mirror mounted on a support measuring $\frac{3}{8}\times 1\frac{1}{4}\times 0.010$ in. which is fastened to a shaft. The shaft has a rod projecting out at 90° to the shaft axis. The rod bears on a cam made by milling a flat face on the end of a steel cylinder to the angle necessary for the required throw of the light beam. A straight wire spring of piano wire was used to press the rod against the cam. The cam, a disk shutter open for about 140°, and a pulley were mounted on the same shaft. The rotating disk

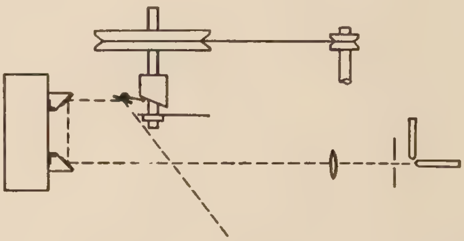


FIG. 3. Optical arrangement. For convenience in illustrating, the oscilloscope has been rotated through 90°.

intercepted the light beam on the return stroke. Both shafts had cone bearings made by drilling the shaft ends with a 60° centering drill and machining cones to fit. This makes it possible to remove all play in the shafts. A variable speed shunt-wound d.c. motor used to drive the unit with a string belt gave very good results for demonstration work. A single reciprocating mirror was used to place successive images in the same position, thus avoiding the careful line-up needed for a many-sided mirror with perfect planes, since any error in the single mirror would be periodic.

Operation. The double oscilloscope is set up with a light source such as a $\frac{1}{4}$-in. diameter rod carbon arc. A metal plate placed in front of the arc (Fig. 3) contains a hole about $\frac{1}{16}$ in. in diameter. A lens is used to focus the light onto the screen after reflection through the oscilloscope and sweep mirrors. For a recent demonstration the double oscilloscope was equipped with mirrors measuring $\frac{3}{8}\times\frac{7}{8}\times 0.011$ in. in order to

secure an amplitude of $1\frac{1}{2}$ ft with a distance of 6 ft between screen and oscilloscope. Due to the weight of the moving elements the frequency range was limited to about 400 cycles/sec. A 60-cycle low voltage wave was fed into oscilloscope No. 1 and shown on the screen. With No. 1 in operation, a 60-cycle wave was fed into oscilloscope No. 2 and the volume control of No. 2 adjusted until the wave form on the screen was reduced to zero amplitude. A 60-cycle wave form modulated by another of about 250 cycles/sec. was also fed into No. 1 and shown on the screen. The resulting wave form was reduced to either 60 or 250 cycle/sec by adjustment of No. 2 and feeding it with the frequency desired to be eliminated.

The apparatus in its present stage of development should be of value in the presentation of the fundamentals of wave composition and resolution.

A Simple Demonstration Telephone Switchboard and Its Operation

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THE demonstration model of a simple common-battery telephone switchboard described herewith possesses the pedagogical advantage that always accompanies the act of simplifying a technical process while still retaining the essential principle. The board is sufficiently open to be visible to a large group and hence lends itself well to demonstration purposes. The present is a strategic time to secure the necessary switchboard units, since so many manually operated switchboards are being discarded in the course of replacement by machine switching equipment. For the construction of the particular board here described, the additional facility of N. Y. A. labor was available, the process of fabrication being educational for the workers and the finished product possessing notable value as an instructional tool.

The board is illustrated in Fig. 1. Upon a 4×6-ft. panel of beaver board are mounted the telephone switchboard units listed in Table I. Diagrammatic wiring is painted on the front of the board connecting the various units or their conventional symbols. Separate batteries are

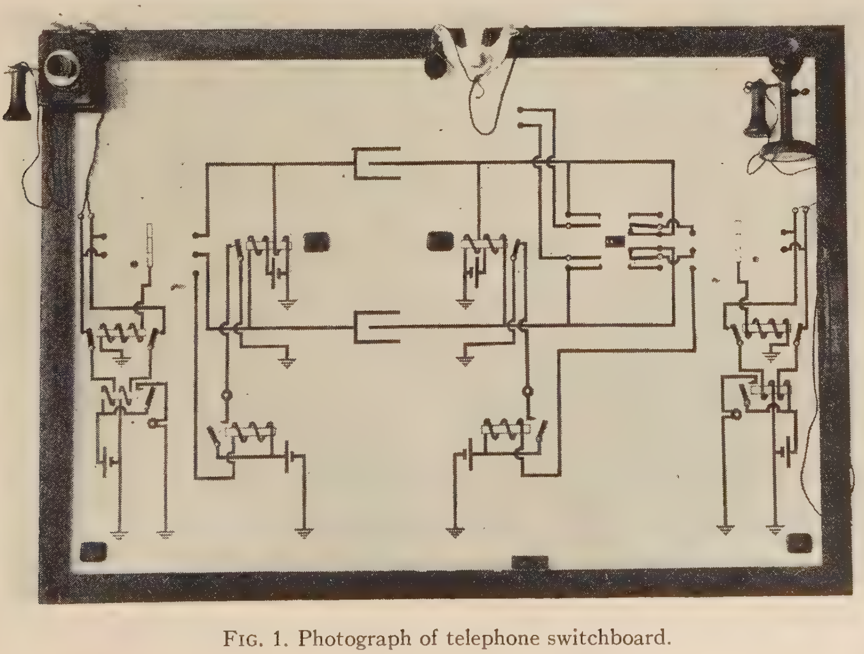


FIG. 1. Photograph of telephone switchboard.

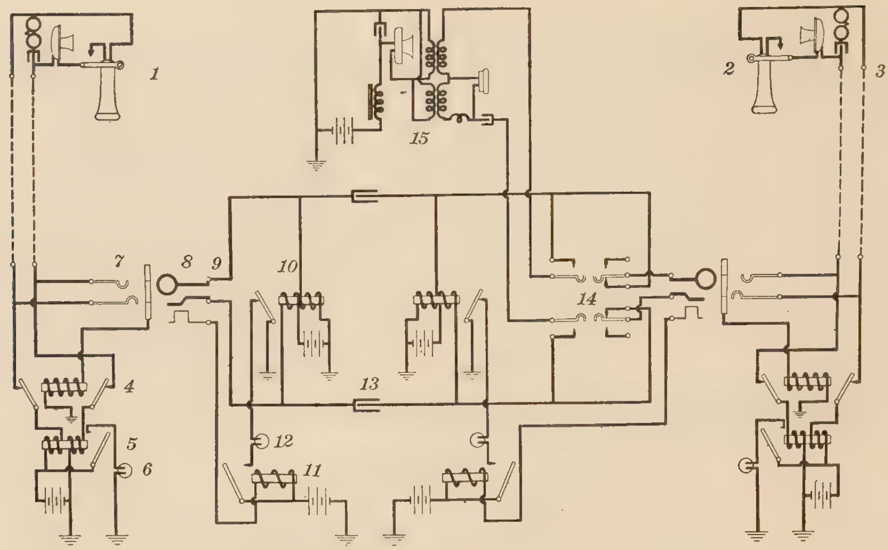


FIG. 2. Normal condition of line.

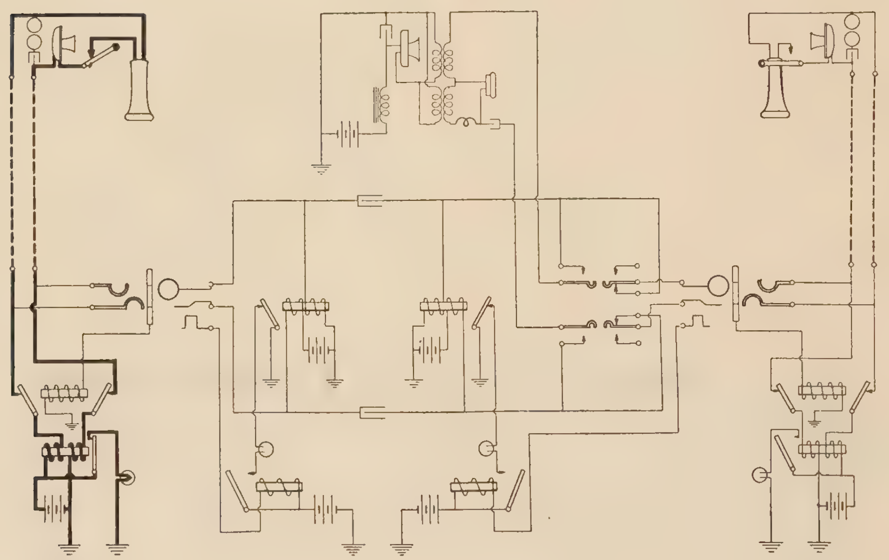


FIG. 3. Subscriber's receiver removed.

indicated, to simplify the diagrammatic wiring. In practice, one 20-v battery supplies the entire board. The relays, too small to be seen except on close inspection, are also represented by conventional symbols. The armatures are made actually movable and are intended to be set by the hand of the demonstrator to illustrate the functions of the relays.

Successive stages in the progress of a call are represented in Figs. 2–8. Lantern slides of these figures form a useful expository aid. In each figure the entire circuit is represented, but heavy lines indicate those portions of the circuit which are of particular importance at that stage, whether the current is actually flowing along the indicated conductors at the moment or not. The two subscribers' telephones are indicated in the two upper corners, the wires connecting them with the central office being indicated by the dotted lines. The remainder of each diagram pertains to the circuits in the central office. The lower two corners show the *relays* and

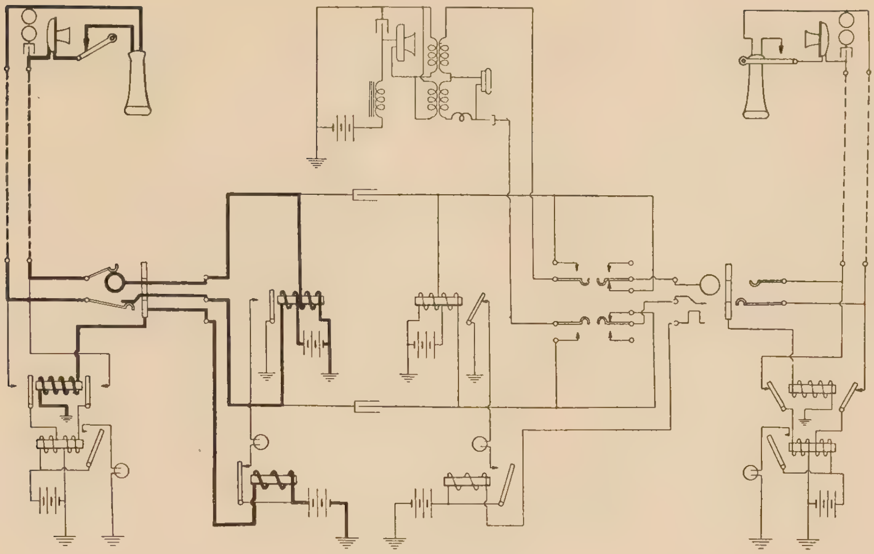


FIG. 4. Operator plugs in.

lamps in which the subscribers' lines terminate at the operator's switchboard. Just above these are the *jacks* by means of which subscribers are connected to the central office and to each other. Opposite these jacks are *plugs* which form the terminals of what is called the *cord circuit;* it occupies most of the central portion of the diagram and includes the several devices by means of which the operator performs the functions of the central office. Just above the cord circuit is the *operator's headset,* the telephone by means of which she speaks and listens to the subscribers. This headset is connected into the circuit by the left-hand side of the *ringing and listening switch.* The right-hand side of the same switch connects the ringing generator (not shown) to the bell of the called subscriber when required.

TABLE I. *Materials required. (Identification numbers as of Kellogg manufacture.)*

No. in Fig. 2	Quantity	Identification No.	Name
			Telephones
1	1	F802	Wall telephone
2	1	F97	Desk set
3	1	F605	Ringer box
			Line Circuit
4	2	2037SR	Cut-off relay, single wound
5	2	2029SAH	Line relay, double wound
6	2	24A	Line lamp, 24-v
7	2	260 or 261	Jack
			Cord Circuit
8	2	106	Plug, 3-conductor
9	2	309TO	Cord, 3-conductor
10	2	2030TJ	Supervisory relay, double wound
11	2	2029SN	Sleeve or signaling relay, single wound
12	2	24A	Supervisory lamps, 24-v
13	2	36	Condensers, 2 μf.
14	1	1029	Combination ringing and listening key
15			Operator's headset, comprising
	1	1076C	Transmitter
	1	65A	Receiver
	1	78A	Induction coil
	2	36	Condensers

For the convenience of readers who may lack familiarity with telephone practice, a brief description of each stage of the establishment of a call is given. A more detailed exposition may be found in standard works on the subject.[1]

Fig. 2 shows the conditions existing before a call is initiated. No current is flowing in any part of the circuit. The function of the condenser which is in series with the subscribers' bells may well be pointed out to the students.

Fig. 3 shows the operation of the subscriber's line lamp (lower left), actuated by the adjacent line relay at the central office. This lamp notifies the operator that the corresponding subscriber desires to place a call. The heavy lines show the current from the subscriber's telephone through the line relay and the circuit in the central office actuated by this relay to light the lamp.

Fig. 4 shows that the insertion of the answering plug of the central-office cord circuit into the jack associated with the line lamp of the calling subscriber, extinguishes the line lamp through the action of the adjacent cut-off relay.

[1] A reference which the authors have found very useful is McMeen and Miller's *Telephony,* rev. ed. (American Technical Society). After this paper was submitted for publication, the authors' attention was called to a film prepared by the Bell Telephone Laboratories entitled "Through the Switchboard." The scenario was written by John Mills, who has courteously arranged for the authors to see the film.

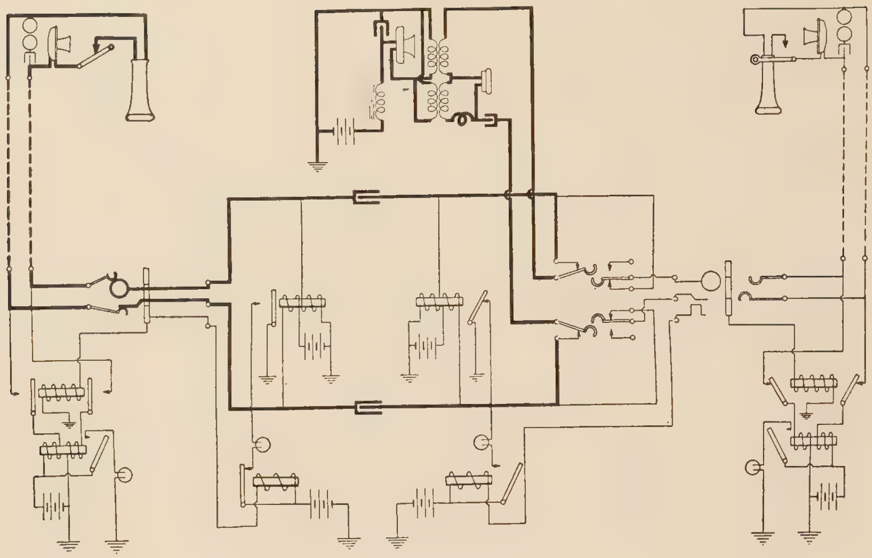


FIG. 5. Operator answers.

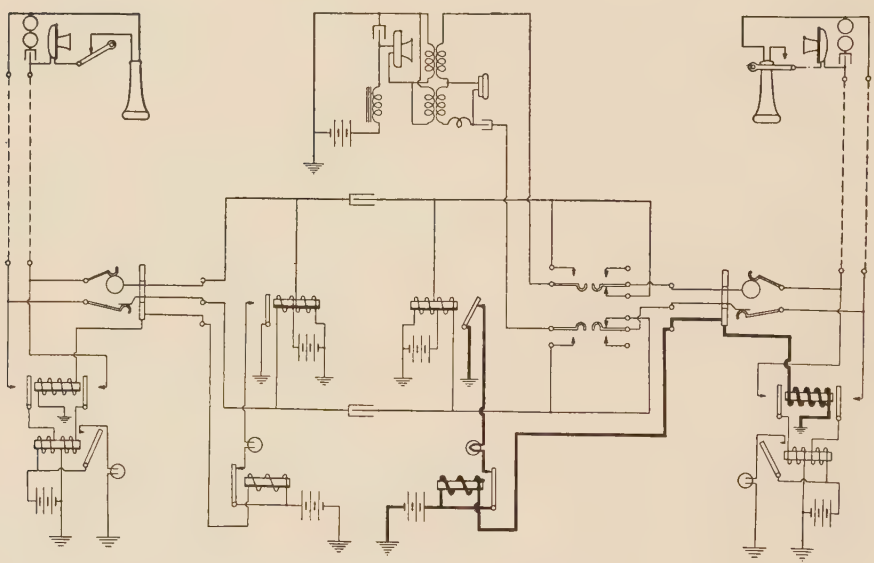


FIG. 6. Operator plugs in called party.

Fig. 5 shows the connection of the operator's headset into the circuit by means of the listening switch at the right center. The subscriber now gives the number of the party he wishes to call.

Fig. 6 shows the illumination of the *supervisory lamp* pertaining to the called party as soon as the calling connection is established. This supervisory lamp, assigned to the subscriber only during the present call, should not be confused with the *line lamp* which is permanently connected to his line at the central office.

Fig. 7 shows the connection of the ringing generator (not shown) from the outside right-hand terminals of the ringing and listening switch to the bell of the subscriber's telephone.

Fig. 8 shows the route of the talking circuit between the two parties. By lifting his receiver the called party extinguishes the supervisory light through the action of the relay in the right center. In this connection the function of the two condensers at the center of the cord circuit may be emphasized.

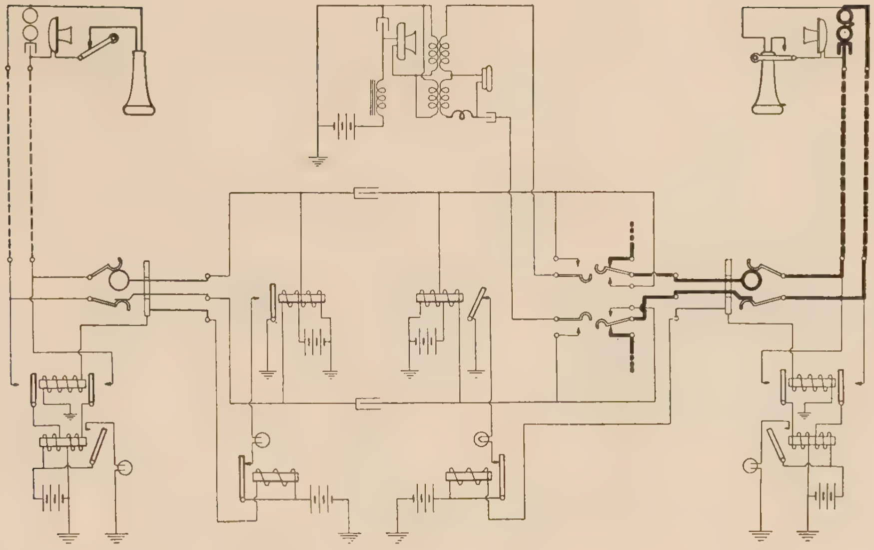


FIG. 7. Operator rings.

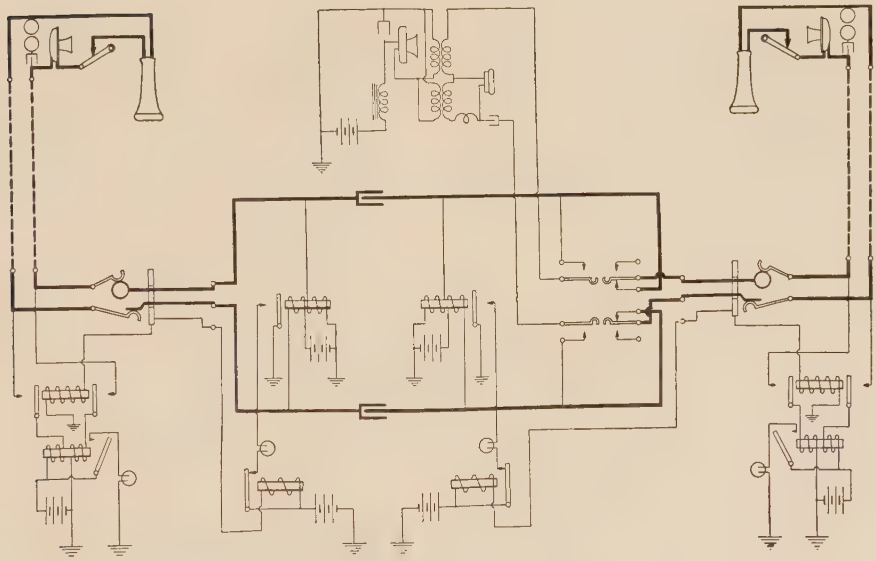


FIG. 8. Called party lifts receiver; talking circuit complete.

Fig. 9 shows the effect of replacing the receivers. Breaking the circuit at station *B* actuates the right-hand supervisory lamp and at station *A* similarly for the left-hand supervisory lamp, each through the action of its respective relay in the cord circuit. With this signal, the operator removes the plugs, thus restoring the circuit to its initial state, ready for another call from any subscriber.

Tracing a call in this way should emphasize the fact that there is no great complication in a single telephone circuit. The impressive array of wires and equipment in a central office is primarily due to multiplication of circuits, each relatively simple. It is to avoid any difficulties due to multiplication of equipment that all reference to multiple jacks, transfer circuits, etc., has been omitted. Any oversimplification that may thereby have been introduced can be considered a counter-irritant to the over-complication that is encountered in any inspection of an actual system.

It is a pleasure to make acknowledgments to

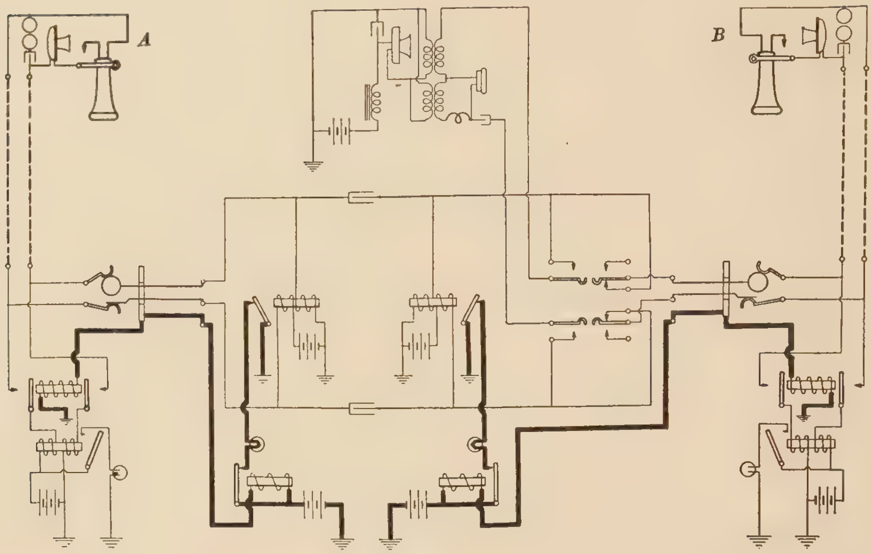


FIG. 9. Call completed; both subscribers hang up.

the N. Y. A. authorities, to its local administration in the person of Miss Ivanore V. Barnes, to Messrs. F. Rudolph Schmidt and Emory W. Sprenkle who worked under the N. Y. A. program, and especially to Mr. D. Alexander, local manager of the Northern Ohio Telephone Company, who provided the necessary switchboard equipment. The original motivation for this undertaking came from the department of physics of Vassar College which possesses a demonstration board of this type. For the loan of the blueprints of their board several years ago the authors express appreciation to the Vassar physics staff.

Abstracts of Contributed Papers, Denver Meeting, June 24, 1937

THE following contributed papers were presented during the morning session of the meeting of the American Association of Physics Teachers held at Denver, Colorado, on June 24, 1937. Abstracts are omitted in the case of papers scheduled for early publication in the journal. A general account of the meeting, with digests of the invited papers given during the afternoon session, appeared in the August issue, page 187.

1. A Polarization Photometer for the Measurement of Low Intensity Light. R. E. NYSWANDER, *University of Denver*.—The photometer was designed for the measurement of weak sources of luminescence. A luminous radium compound of zinc sulfide, in a small glass tube placed back of two Nicol prisms arranged end to end, serves as a standard of illumination. The second Nicol from the standard source is mounted so that it may be rotated and carries a pointer moving over a scale graduated in degrees which indicates the angle necessary to establish a balance between the two sources of light. The standard source of light and the two Nicols are mounted in a tube which is attached at right angles to the main photometer tube so that light from the standard source is reflected down its length to the eye of the observer by means of a right angled prism. The source to be measured is viewed directly down this tube alongside the light from the standard source. Light intensity is proportional to the square of the cosine of the angle between the principal sections of the two Nicol prisms. Values of light intensities obtained by the cosine square curve agree closely with observed values secured by calibrating the instrument with a photoelectric cell.

2. The Use of Commercial Tubes in Determining Resonance and Ionization Potentials. J. C. STEARNS, *University of Denver*.—Four tubes, FG17, FG27, 256A and 885, were tested, the method of K. T. Compton being employed. The galvanometer had a constant of 10^{-9}

amp./div. It was not possible to detect a resonance potential with any tube save the 885. In this case the background masked the maximums and minimums. By the treatment of finite differences it is possible to establish the resonance and ionization potentials when the 885 is employed. The FG27 is suitable for determining the ionization potential of mercury and might show a resonance potential with a more sensitive galvanometer. The 256A is not suitable for either, and special precautions must be taken with the FG17 to secure correct results. When the grid voltage of either of these tubes is increased beyond the ionization potential, an arc is formed with an increase in plate current and a fall in grid voltage. It is easy to establish the negative resistance of the tube under this condition.

3. **An Adjustable Constant Temperature Oven for Measuring Temperature Coefficients of Resistance.** F. C. Walz, R. V. Cartwright and W. B. Pietenpol, *University of Colorado.*—A constant temperature oven was designed to give three different temperatures in a minimum of time. It consists of a thick-walled aluminum box within a box of soft wood which is inside of another box of balsa wood. Three thermostats connected to a selector switch are mounted in the space between the aluminum and the soft-wood box. The thermostatically controlled heaters are mounted between the two wooden boxes. To permit temperature changes to be made rapidly, two fans mounted on the same motor shaft are used to circulate the air inside the aluminum box, and the heated air into the soft-wood box and around the aluminum box. By overheating the inside of the aluminum box with an auxiliary heater which is disconnected automatically by the first cut-off of a thermostat, the time for reaching a constant temperature inside the aluminum box is decreased from over 2 hr. to 30 min. Three coils of copper, of nichrome, and of manganin wire, respectively, are mounted inside the oven and are connected to selector switches by two current and two potential leads. Their resistances can then be measured independently of the lead resistances by means of a potentiometer. The temperatures are measured with high grade thermometers.

4. **Laboratory Uses for Pyrex Glass Welds to Metals.** Byron E. Cohn, *University of Denver.*—Welds of Pyrex glass to platinum, palladium, and copper were discussed and several uses described. A simple dew-point apparatus which makes use of a nickel-plated copper seal to Pyrex glass and a direct weld of Pyrex glass to a palladium tube was exhibited.

5. **An Inexpensive Tachometer of High Accuracy.** F. C. Walz and R. V. Cartwright, *University of Colorado.*—An accurate, inexpensive tachometer can be made from apparatus ordinarily available. By separately exciting the field of a small 6-v d.c. automobile fan motor, a 0–1 milliammeter having the proper value of series resistance and connected across the armature can be calibrated to read motor speeds directly. The milliammeter can also be used as an ammeter to adjust the field current to the same value by connecting it across a resistance in the field circuit as a shunt. Various ranges can be obtained by choosing different values of resistance in series with the armature. Since the e.m.f. of the armature varies linearly with speed it is only necessary to secure one point on the meter scale by means of a synchronous motor of known speed to calibrate the tachometer. The accuracy of the tachometer is the same as that of the meter used. To assure linearity between e.m.f. and speed, it is important to use sufficient field excitation, about 0.5 amp. for the particular motor used. The field current must be maintained in the same direction as that used when the instrument was calibrated.

6. **Inexpensive Apparatus for Lecture and Laboratory Demonstrations in Polarized Light.** Leighton B. Morse, *College of the City of New York.*

7. **Laboratory Work in the General Physics Course for Engineering Students.** Philo F. Hammond, *University of Wyoming.*

8. **Wrong Treatment of Electric and Magnetic Quantities in Beginning Texts.** Edward M. Little, *Montana State University.*—At least three-fourths of the general physics texts treat permeability and induction B wrongly. Lines of force and lines of induction are confused; permeability is said to be the ease with which lines of force are produced in a medium; etc. As a matter of fact, permeability is the difficulty with which lines of force are set up by a magnet, although it does also happen to be the ease with which lines of induction are set up by a current. It was shown in the paper that the force between two magnets is proportional to the first power of the permeability; between a magnet and a current, the zero power; between a current and a current, the negative first power. Now that H has appropriated the reluctance unit (oersted), and given its unit (gauss) to B, which previously had no unit of its own, part of the confusion will be cleared up. Contrary to some prevalent opinions it is B, not H, that is the important concept in most applications of electromagnetics; both e.m.f. generated and force on a current are proportional to B, not H. Also contrary to prevalent belief, the magnetic field due to a current is independent of the permeability.

9. **A Comparison of the Effectiveness of the Demonstration Method and of Individual Laboratory Work in the Teaching of Physics in Secondary Schools.** Julian M. Blair, *University of Colorado.*—A survey was presented of studies of the relative effectiveness of demonstrations and individual laboratory work. The demonstration method appears to be superior, although this conclusion is not final because of the small amount of evidence accumulated.

10. **Physics for Students in the Premedical and in the Biological Courses.** E. L. Harrington, *University of Saskatchewan.*—A special course in physics for students preparing for medicine or for biology is given at the University of Saskatchewan. This course has grown in popu-

larity during the ten years it has been evolving, and is now elected by many who do not belong to either of the foregoing groups. The medical students who have had the course find that they can apply their training in physics to their work in medicine to an extent far greater than can those who have taken more conventional courses.

11. On the Academic Training in Physics of the Teachers of Physics in the High Schools of Illinois. LESTER I. BOCKSTAHLER, *Northwestern University.*—As a partial guide in planning the content of a college course in the teaching of physics in secondary schools, practically all of the teachers of physics in the high schools of Illinois were asked to indicate what courses in physics they had studied. Replies were received from 75 percent of those teaching physics. They show that 36 percent (32 percent exclusive of Chicago) of the teachers have a college degree with physics as the major subject, while 97 percent have completed a year of general college physics. The percentages of teachers who have studied courses in physics in addition to the one year general college course are as follows: mechanics, 49; heat, 48; sound, 35; light, 47; electricity, 63; "other" (radio, engineering, meteorology, etc.), 43. On the basis of the number of courses studied in addition to the general course, it appears that the percentage who have had one course only is 13; two courses, 13; three courses, 12; four courses, 9; five courses, 12; six or more courses, 23; while 18 percent have had no work in physics beyond the general course. The group of teachers with college degrees and major in physics had in their classes 50 percent of the pupils studying physics in the high schools of the state. This study is being continued to determine just what topics in a training course the teachers themselves feel would aid them most in their training.

12. Some Tentative Conclusions from the Three-Year College Testing Program. C. J. LAPP, *University of Iowa.*—(1) Little difference in achievement can be found favoring specific textbooks, specific divisions of time given to laboratory and lecture, a given size of class or group of institutions arranged according to professional plans; (2) There are tremendous individual differences between students; and from college to college; and in the gains made by the students in a given course; (3) Those students who have had secondary school physics do distinctly better both as to gain and final achievement than those who have not had it; (4) Students classified as engineers have the best achievement of any group; (5) Over the nation, students getting 5 hours credits per semester achieve about the same as those getting 4 hours credit; (6) The tests for the first three years show almost equal difficulty.

13. Physics in the Modern High School. HUGH T. BEAVER, *Colorado State Preparatory School.*—Increasing pressure on the secondary school toward an enlarged curriculum offering, mainly due to enormously increased enrolments, is a phenomenon of the present period in education. In 1890, nine subjects, including physics, were taught; in 1928 the number had increased to 47 and, though restricted somewhat during depression years, is again increasing. Physics still enrols 7 to 14 percent of the students, and is given as an elective in the third or fourth year. The organization of the subject is practically the same as in 1890, but content and method have changed. Many schools offer a nonmathematical course, known as Descriptive Physics, for those who do not plan to attend college; it substitutes reference work and reports along topical lines for problems, among these being biographies, modern appliances, and special applications of physical principles. Other courses offered which are largely or partly physics include Junior Science, Senior Science, Related Science for Vocational students, Shop Mathematics, etc. Considerable controversy exists today in teaching methods in physics. Independent, individual work is much advocated, especially by the Progressive Education group; it eliminates group assignments, discussion, and experiments, and allows each pupil to proceed at his own pace. Some tests on this method seem to show that the brighter students do better work and the lower quartile pupils, poorer work.

14. Concerning Definitions in General Physics. MALCOLM C. HYLAN, *University of Colorado.*—A primary objective of a course in general college physics should be to teach the student to think scientifically. To that end the course itself should be a model of logic and straightforward presentation, and this depends largely on the accuracy and logic of the definitions. Referring particularly to electricity and magnetism, the author suggested that there should be given first a general definition of each electrical quantity, and then a general definition of the unit of that quantity which, by a change of a few words, would serve for either the electrostatic, the electromagnetic or the practical system. He would tie the practical system to the electromagnetic system, from which it is derived theoretically, by but one direct relation, namely, 1 amp. = 0.1 e.m.u. This method emphasizes more clearly the idea that the fundamental relations such as $E=IR$, $Q=It$ and $C=Q/V$ are truly universal and hold in every system. The student then can easily compute for himself the relations between the units of the several systems. The international practical units would be mentioned simply to explain their *raison d'etre*, and would not be used in any theoretical discussion.

NOTES ON APPARATUS AND DEMONSTRATIONS

Demonstration of Lissajous' Figures

VARIOUS forms of apparatus have been designed for the experimental tracing of Lissajous' figures but except in one or two cases (for example, the cathode-ray oscillograph) the arrangements have not permitted an easy and continuous adjustment of the frequency of one of the vibrators with respect to the other. This desirable feature is incorporated in the present simple apparatus. Furthermore, its optical system enables photographic records of the tracings to be easily obtained.

Figures 1 and 2 show the general construction. A light metal plate pierced with a narrow vertical slit is fixed to one prong of a 50-cycle maintained fork so that it moves in a vertical plane perpendicular to a horizontal slit in a similar plate P. The latter consists of a flat piece of tinned iron securely clamped to two sonometer wires by bending over the top and bottom ends. These wires are mounted in a frame formed by two horizontal bars A and B, each 18 in. long, which are held about 4 in. apart by rods C and D. An electromagnet E is fixed at the center of A and, directly below it, a mercury-contact system R is rigidly attached to B. One end of the coil of the electromagnet is connected to one pole of a secondary battery; the other end is permanently connected to the frame, and hence to the wires and P. If the remaining pole of the battery is joined to R the electrical circuit is completed, on the depression of P, through a short platinum wire soldered to the plate.

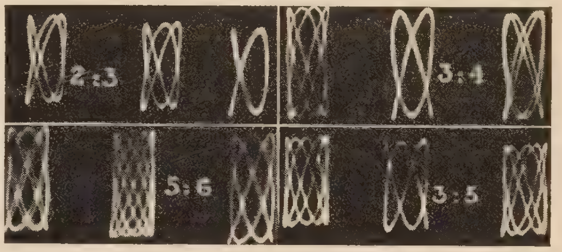
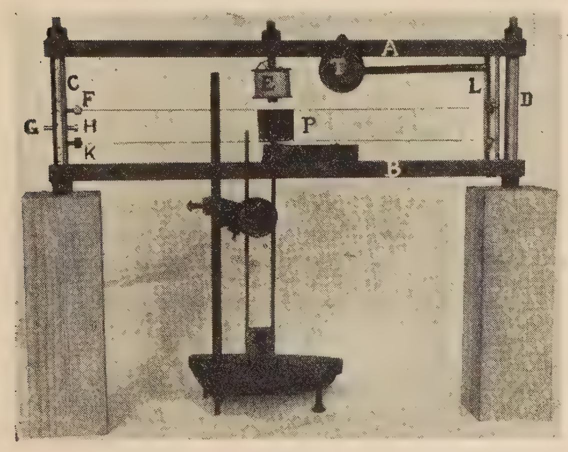
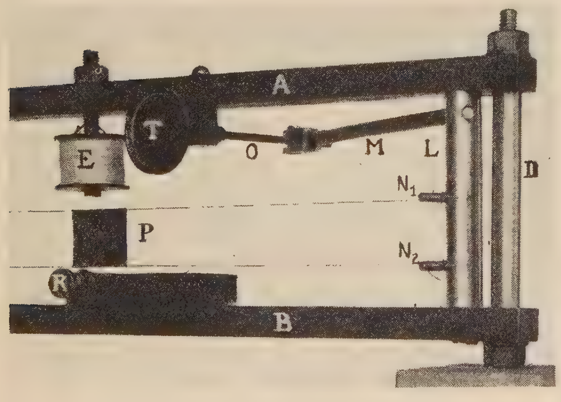


FIG. 3. Lissajous' figures.

The sonometer-wire system consists of a length of steel pianoforte wire which is threaded through fine holes at F and K before its ends are fixed to the pegs N_1 and N_2. The wire is also carried over the rod G which can be moved horizontally by the screw H, to absorb any initial slackness. By means of nuts screwed on the split ends of F and K, the wires can be effectively clamped.

The force in the wires is adjusted by a simple mechanism for turning the roller L, to which the pegs N_1 and N_2 are rigidly fixed. This rotation is effected by means of a threaded rod O working in a pivoted nut at the end of the lever M, the other end of the lever being securely fixed in L. By employing the optical system of a stereopticon, light is focused on the slits and then projected on a screen, and the figures may be held in any position by suitable manipulation of the knob T. The photographs in Fig. 3 were obtained with exposures of the order of 1 sec.





FIGS. 1 AND 2. Photographs of apparatus.

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R. W. B. STEPHENS

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A Lecture Demonstration of the Law of Conservation of Mass

A SATISFACTORY lecture demonstration of the law of the conservation of mass may be made with the aid of one of the photoflash bulbs which have been developed to expedite indoor and night photography. These bulbs, which are similar in size and shape to an ordinary incandescent lamp, contain a piece of rumpled up aluminum foil in an atmosphere of oxygen and a small piece of fuse wire connected to the two outlets in the base. Any difference of potential of about 2 v or more will burn out the fuse, thus igniting the aluminum foil which burns with a brilliant flash. We have, therefore, in this commercial product a violent chemical reaction taking place in a sealed system.

One satisfactory way to conduct the demonstration is to wipe the bulb carefully with a dry towel, place it on a pan of one of the ordinary beam balances used in lecture demonstrations, and balance it with suitable weights. This much can well be done before class. The bulb can then be picked up using a towel or pair of cloth gloves and inserted in an ordinary lamp socket connected to the lighting circuit. When the circuit is closed, the students observe the blinding flash as the aluminum is consumed and globules of fused aluminum oxide form on the inner surface of the bulb. If, now, the bulb, handled as before, is replaced on the balance pan, it will be found to be balanced by the same weights as beforehand.

Except for accidental changes due to careless handling, the most sensitive analytical balance should show no change in the mass of the system due to the reaction. However, in order to be able to perform the experiment in class conveniently, and in reasonable time, a demonstration balance with a sensitivity of only about 0.01 g/div. is probably most satisfactory.

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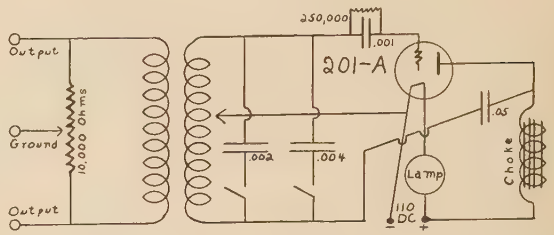
An Audio-Frequency Generator for Laboratory Use

IN a modern laboratory one needs a source of audio-frequency current to use when measuring inductance, capacitance and impedance. Most laboratories are equipped with commercial 60-cycle current but this frequency is low for audio work. The frequency of the generator should be in the neighborhood of 796 ($\omega = 5000$) or 1000 cycles/sec. This source should be available at all times or should consist of a small portable generator which can be started at a moment's notice. Such a generator can be made with the modern tube used as an oscillator; but this must be supplied with A- and B-voltages, and batteries are expensive and inconvenient. The usual a.c. supply outfits are heavy and not satisfactory unless well filtered.



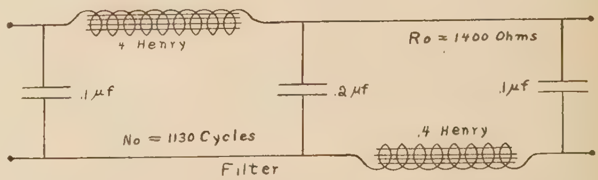


Fig. 1. (Above) Circuit of generator. Fig. 2. (Below) A two-section π-filter for removing harmonics from a 800-cycle generator.

If a 110-v d.c. supply is available an inexpensive oscillator can be made and mounted on a wooden base of small dimensions so as to be as portable as the ordinary resistance box. Any three-electrode tube can be used provided the plate potential required is near 100 v. For example, the 201A tube, with a filament current of $\frac{1}{4}$ amp, will oscillate with 100-v on the plate. A 30-w lamp connected in series with the tube filament limits the current to about $\frac{1}{4}$ amp when connected to the 110-v circuit; the lamp is connected to the positive terminal of the d.c. circuit and the filament to the negative terminal. The coil used is a replacement coil for an audio transformer. The primary coil has a mid-tap. This coil is connected in the usual manner for a Hartley shunt circuit as shown in Fig. 1. The audio choke can be the good coil in an old interstage transformer. The tuning condensers will have values close to those marked in

Table I. *Input impedance of bridge, 2500 ohms; loudspeaker impedance, 2650 ohms. Maximun change of frequency during measurment, requiring 30 min., 27 cycles or 3.4 percent.*

	Frequency	Swing	Accuracy (percent)	Harmonic volt
1. Bridge alone	793	4	0.5	0.01
2. Bridge paralleled with filter	787	4	.5	.01
3. Bridge paralleled with speaker	783	10	1.3	.01
4. Bridge connected to output of filter	805	3	.4	.00
5. Bridge and loudspeaker paralleled on output of filter	810	6	.8	.01
6. Bridge as in case 1	801	4	.4	.01
7. Generator in bridge	985	3	.55	.075
8. Tube generator without grid condenser and leak	800	20	2.5	.6

the diagram, although the exact values should be selected to give the frequency wanted. The grid condenser and grid-leak resistance can be omitted but the wave form is improved when they are present. A 10,000-ohm potentiometer placed across the output terminals and used as a Wagner ground is a great convenience. The output terminals, being connected to the close-coupled secondary, have no conductive connection with the 110-v circuit.

The output impedance of the generator is about 1500 ohms. The open-circuit voltage is 12 v, as measured with a 4000-ohm output meter. This voltage is enough for all ordinary capacitance, inductance, and impedance bridge measurements without an amplifier if good headphones are used. With N and F phones measurements can be made in the laboratory while other students are using such apparatus as buzzers and oscillators. When the generator is matched to a good loudspeaker the sound output is comfortably loud.

The frequency changes some with load and line voltage, as will be shown in Table I, and hence the oscillator cannot be used when measuring capacitance or inductance in a frequency bridge. For capacitance and inductance bridges where frequency is not a factor in the method, it serves admirably. A simple filter made of telephone coils and condensers (Fig. 2) removes most of the harmonics and the resulting output curve, as viewed in a cathode-ray oscilloscope, is a sine curve.

The data given in Table I will give an idea of the frequency change in actual practice and also the harmonic voltage remaining after balancing out the fundamental with a frequency bridge. The frequency is measured by placing 500-mh inductance in series with 0.1- or 0.2-μf capacitance, measuring the outstanding inductance, and then calculating the frequency by means of the formula, $n=1/2\pi(LC)^{\frac{1}{2}}$. The percentage error is found by swinging the dial between high and low values, from the point the observer is just sure the dial is too high to the point where he is just sure it is too low. It is assumed that half of this swing compared with the inductance in the resonant circuit gives the accuracy of the inductance measurement. Since the inductance enters into the frequency calculation as the square root, the percentage error of the frequency is half that of the inductance. Harmonics and room noises will increase these errors; when the loudspeaker is connected the sound from it makes the readings less accurate. The impedance bridge contained a generator and data are given for this generator. A single reading is given for an oscillator made as described above but with the grid condenser and grid leak omitted.

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Apparatus for Exciting the Spectrum of Atomic Hydrogen

ALTHOUGH methods for exciting the spectrum of atomic hydrogen are rather well known it is believed that the simplicity of the apparatus used here justifies its description. Fig. 1 shows the discharge tube and the

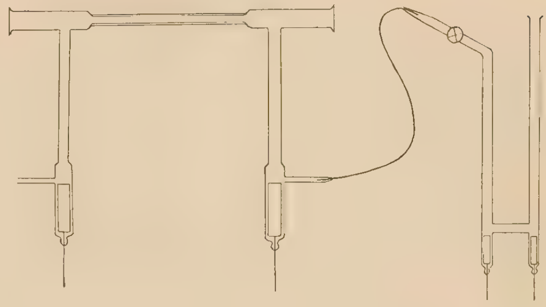

Fig. 1. Schematic diagram of apparatus.

hydrogen generator, which are made of Pyrex glass. The dimensions are not critical. An over-all length of 10 or 12 in. for the discharge tube is satisfactory. The constricted section has an internal diameter of 4 or 5 mm. For maximum intensity the tube should be viewed end on through plane windows which may be cemented to the flanged tube with sealing wax, or the glass may be sealed off and blown into a half-sphere. The electrodes, which are large to avoid overheating, are about 5/8 in. in diameter and 1.5 in. long. They may be made of sheet aluminum rolled into compact cylinders, or of solid aluminum. They are fastened to heavy tungsten leads which are sealed through the glass in the usual manner. The tube is operated from a small 2000 to 10,000-v transformer. No cooling bath is necessary.

The hydrogen is generated electrolytically and is used without drying because the presence of water vapor on the walls of the discharge tube hinders the emission of the molecular spectrum. The electrodes of the hydrogen generator are made of platinum foil attached to tungsten wire. The hydrogen flows from the generator to the discharge tube through a fine capillary drawn from glass tubing. The capillary is joined on with sealing wax and can therefore be replaced very easily if the size is not satisfactory. A stopcock in the line helps to control the rate of flow which is maintained by an oil vacuum pump.

The most favorable pressure is obtained by trial. When functioning properly the discharge has a reddish color, and the striations in the side arms are spaced about 1 cm apart. Under these conditions the first three or four lines in the Balmer series are plainly visible when the horizontal section of the tube is viewed with a diffraction grating replica or a small spectroscope.

If apparatus for photographing the spectrum is not available visual measurements can be made with sufficient accuracy to give a fairly good check of the Balmer formula. The apparatus is suitable for a lecture demonstration if grating replicas are distributed to the class. In our laboratory a 10-ft. grating in Eagle mounting has been used to make the experiment one of considerable precision. This spectrograph was constructed with sufficient accuracy to permit the focusing adjustments to be made by calculation which further enhances the instructional value of the experiment.

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An Easily Constructed Camera for Use in Making Lantern Slides

IT is possible to construct easily and at practically no cost a focusing camera which may be used in making lantern slides and photostatic copies, or in any other photographic work where speed in exposure is not essential.

In Fig. 1, C is a crayon box with one end removed and

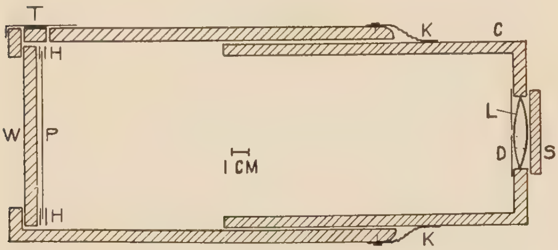

FIG. 1. Diagram of the camera.

in the other end of which has been mounted a thirty-cent laboratory lens L of focal length 15 cm. A diaphragm D containing a 3-mm hole is placed behind the lens and a wooden lever S, mounted on a screw as an axis, serves as a shutter. Telescoping the crayon box is another close fitting box, in the rear end of which is a cardboard frame H for holding the lantern slide plate P. A removable section T of the top, made by cementing black cardboard to a strip of wood, permits the insertion of the plate. Focusing is accomplished by removing the camera back W (Fig. 2*b*), placing a ground glass plate (made from a lantern slide cover plate) in the plate holder, and sliding one box within the other. The inside of each box is painted a dull black. Entrance of light is prevented by a collar of black sateen thumb-tacked to the outer box and held snugly at K by an elastic band.

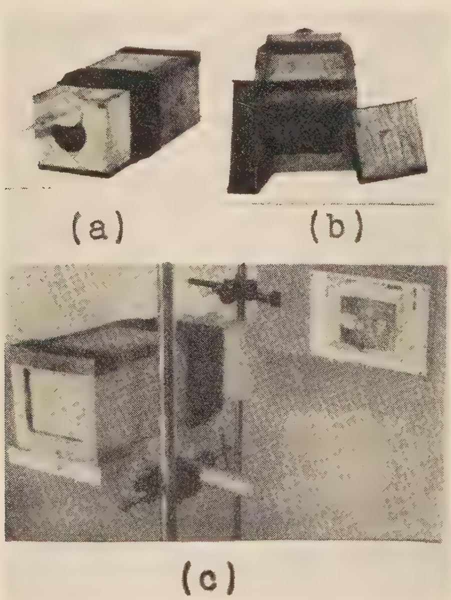

FIG. 2. (a) Front view. (b) Rear view, with camera back W and top section T removed. (c) Camera in position for making photograph.

In practice, the camera is placed on a platform attached to an iron support (Fig. 2c) and focused; it is then removed to the dark room, the plate inserted, and then carefully replaced in its original position on the platform. Exposure times of from 30 sec. for printed matter and line drawings to 5 min. for some pieces of apparatus are required, the illumination used being diffuse daylight. A print of a typical slide is shown in Fig. 3. The accuracy with which typed material is reproduced may be seen from the lettering in Fig. 2, which was copied with the camera from a set of small kodak pictures.

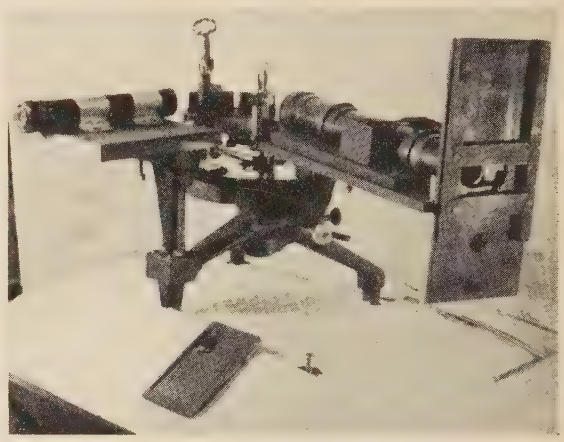

FIG. 3. A typical slide, showing a two-prism spectrograph improvised for studying Raman spectra.

The author desires to express his appreciation to Mr. Woodrow Hammock for assistance in the construction and development work, and to Dr. M. J. Murray for permission to use the slide reproduced in Fig. 3.

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Colored Motion Photomicrography of the Formation of Crystals in Polarized Light

POSSIBLY the most strikingly beautiful phenomenon in the entire field of the physical sciences is the formation of crystals as viewed through a low power microscope with polarized light. The high cost of a polarizing microscope has in the past been a hindrance, but with the development of polarizing films of wide aperture and low cost, these phenomena can now be shown in any physics laboratory. The author has found a binocular microscope of wide field and low power to be most satisfactory for visual work. Magnifications of from 12.5 to 20 diameters are favorable. A convenient frame can be made for mounting the polarizer and analyzer in such a manner that a microscope slide can be inserted between them, and the entire unit mounted on the stage of the microscope.

FIG. 1. Photograph of apparatus.

Large numbers of crystals are known to give beautiful patterns. Besides the necessary property of double refraction, the crystal must have a low melting point if the crystalization process itself is to be observed. The most satisfactory crystal known to the author is acetamid. It melts readily, crystallizes rapidly and yields remarkably beautiful color patterns. These crystals may be prepared by gently warming two microscope slides, placing a small quantity of acetamid on one of them and covering it with the second. When allowed to cool for a few seconds, crystallization sets in and proceeds at a rapid rate until the entire slide is covered with the needle-like structures.

Inasmuch as visual observation with a microscope is not adaptable to large group demonstration, the author made colored motion photomicrographs of the phenomena. While the literature on the subject of motion photomicrography is not extensive, the process is well known.[1] The arrangement of apparatus for 16-mm pictures as used by the author is shown in Figs. 1 and 2. Since it is necessary to see the field of view while the pictures are being taken in order that the operator may focus the microscope slide without interrupting the photographic process, a "beam splitter" of some form is needed. The camera should be mounted so that the light-lock between microscope and camera opens in the same direction as the axis of the microscope, otherwise there exists the extreme inconvenience of readjusting the camera support each time the microscope is refocused. To accomplish this end a demonstration eyepiece (Fig. 3) was inserted in place of the ocular of a standard monocular microscope with substage condenser. The light-lock between the eyepiece and camera was formed by mounting with liquid solder, a small brass collar over the vertical eyelens of the beam splitter. The collar was approximately 8 mm high and of such a diameter as to fit freely but not loosely inside the cylindrical housing of the camera objective. After proper focusing and adjustment of the light-lock between microscope and camera a strip of black cloth was wound loosely around the connection to exclude stray light. To reduce the vibration of the camera to a minimum and at the same time prevent all camera vibration being transmitted to the microscope, it is essential that the camera support be massive and not connected in any way with the microscope.

Low power magnification was obtained by removing the front lens of a 10× objective. The result was a wide field objective of 4 diameters. Since the eyelens of the demonstration eyepiece gave a magnification of 6.4 diameters, a total magnification of approximately 25 diameters was obtained. It is desirable for motion photomicrography to use slightly greater magnification than for visual work.

The source of illumination was a Spencer microscope lamp No. 370 with 100-w, 115-v monoplane filament. The question of illumination proved to be the most difficult in the entire operation. Kodachrome A film for artificial light requires slightly more than twice the illumination needed for Ciné-Kodak panchromatic film at the same camera speed. Since the color of the frames is affected by the color of the light source, no corrective blue filter should be used.

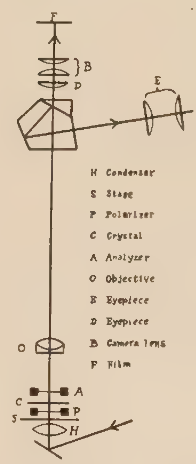

FIG. 2. Arrangement of apparatus.

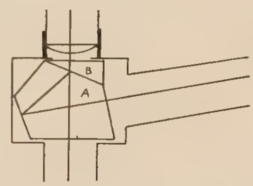

FIG. 3.

It is to be emphasized that lens aperture and intensity of illumination can be determined only by individual experimentation since these variables are governed by conditions peculiar to the individual circumstances. For this reason, a roll of test exposures was made under varying conditions of aperture and intensity of illumination. These test exposures showed that satisfactory results might be obtained with lens speed *f:* 2.7 for normal camera speed of operation. Kodachrome A film thus exposed, yielded beautiful pictures of the crystal formation.

The author wishes to express his indebtedness to Mr. B. L. Hawkins of the department of biology for valuable assistance and suggestions on the technic of photomicrography and for the use of certain equipment.

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[1] *Photomicrography* (Eastman Kodak Co.).

Some Experiments in Mechanics for the Elementary Laboratory *

IN designing experiments for the elementary laboratory the instructor often strives for elegance and accuracy at the expense of simplicity and directness. It is the author's belief that several important physical principles are being neglected in the laboratory because the student, in performing an experiment by some highly accurate method, finds in the end that the apparatus is so complicated or the procedure so involved that he really does not understand what he has done. Thus, the instructor discards such experiments as being unsuitable or else drives the student through them because they are recognized as "elegant." More might be gained if the student were allowed to use simple apparatus whose working principle could easily be grasped and then were encouraged to develop his own procedure as much as possible. Training in precision methods of measurement may not be the whole function of the elementary laboratory.

The physical pendulum. An excellent example of a principle that is not being emphasized in the laboratory is that of the physical pendulum. The theory dates from the time of Huygens and may be found in most of the older texts on mechanics. But few, if any, modern laboratory texts mention the physical pendulum, other than the Kater pendulum which, after all, is a very special type.

A successful experiment for teaching this principle has been used by us for some time. The pendulum is simply a large board of irregular shape and uniform thickness, suspended by thrusting into it from opposite sides two needle-point bearings (Fig. 1). If the needles are loosened slightly and the pendulum displaced through a small angle, it will oscillate fifty or a hundred times before coming to rest.

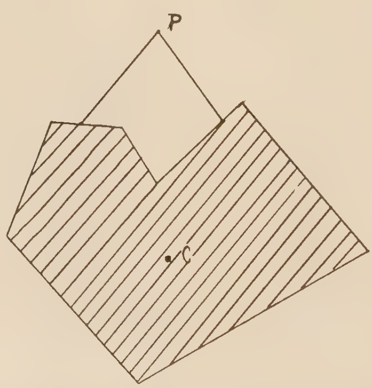
Before suspending the board it is covered on one side with a sheet of paper held by thumb tacks. The center of gravity C is located with the help of a plumb line in the familiar manner. Then with C as the center a large circle of some radius R_1 is drawn. Only a few points on the circumference of this circle need fall on the board. The board is then suspended in succession at several points on this circumference and each time its period is measured with a stop watch. Of course, the period should be the same for all these points.

Now starting near the center C, we determine the period for various other axes until one is located for which the period is the same as for axes through points on the circle. It is possible, of course, that no such axes will be found within the circle, in which case points outside should be examined. Points off the board may be investigated by suspending the board by a string (Fig. 2). When a point is located, its distance R_2 from the center of gravity is measured, and, if possible, a circle is drawn about C with R_2 as radius. The period determined for various points on this circle should be equal to that for points on the first circle.[1]

A simple pendulum of length R_1+R_2 is now made and its period determined. The period should be equal to that of the physical pendulum when suspended at any point on either of the two circles.

Thus it is shown that if any object is suspended so as to oscillate as a pendulum about an axis distant R_1 from its center of gravity, then: (1) its period will be the same for any parallel axis distant R_1 from the center of gravity; (2) in general, there exists another circle of radius R_2 which is the locus of parallel axes for which the period will be the same as for parallel axes through points on the circle of radius R_1; (3) this period will be equal to that of a simple pendulum of length R_1+R_2. With these general laws established it is easy to proceed to applications such as the Kater pendulum.

Falling body apparatus. We have used the apparatus shown in Fig. 3 with marked success. The Cenco impulse counter C is connected through a suitable resistance to a low voltage transformer Tr in series with a spring switch L. Normally this switch is kept closed by the tension in the spring. Another spring switch S serves as a release and normally is shunted across the impulse counter. So long as



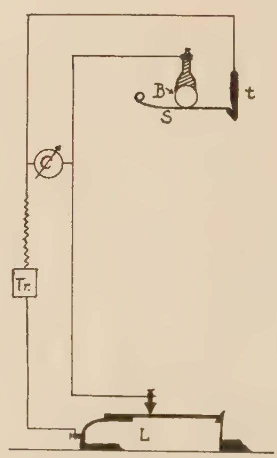


FIG. 1. (Left) Physical pendulum. FIG. 2. (Center) Case where the axis is off the board.
FIG. 3. (Right) Falling body apparatus.

S is closed the counter will not operate. When the trigger t is released, S springs away and releases the ball B. This sets up a current through the counter C and starts it operating. When the ball strikes L, the circuit is opened and the counter stopped. A spring catch is arranged to engage L so that it will not fly up and start the counter when the ball rolls off.

When the counter is used on 60-cycle current, it counts each 1/120 sec., and thus the time of fall is known with this accuracy. If the distance fallen is 12 ft. or more, the apparatus should be accurate to 1 percent and to nearly this figure for distances greater than 4 ft. In performing the experiment the observer should find the *shortest* distance for which a given time will be indicated by the counter. Thus, if the reading was 1 sec. upon the first trial, the contact L should be raised gradually until a reading of 119/120 is indicated, then lowered a bit until 1 sec. is again obtained. This procedure is necessary since the counter-hand does not move continuously, but jumps one division each time the current in it reaches a maximum.

The apparatus is easily made and the parts cost practically nothing. Moreover, the experiment is quite instructive and has been found to be practically fool proof.

Pascal's law apparatus. The pressure is exerted on a plug which is suspended from one arm of an equal-arm balance so as to move freely in a brass cylinder. Water is passed into the cylinder above the plug to compensate for that which leaks past it. Thus the height of water above the plug can be maintained at any given level. Vessels of various sizes and shapes may be screwed to the upper end of the cylinder. When water columns up to 80 cm in height are used, accuracies up to 0.25 percent may be attained.

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* Paper No. 471; Journal Series, University of Arkansas.

[1] It is possible that having drawn the circle of radius R_1 no other circle of different radius can be found for which the period is the same. In this case $R_1=R_2$. However, if R_1 is chosen at random, this is not likely to occur.

Modification of the Traditional Demonstration of the e.m.f. of Self-Induction

IN the traditional demonstration of the phenomena of self-induction described in elementary textbooks, an incandescent lamp is connected in parallel with a coil of large inductance, and changes in the intensity of the illumination are observed as the main circuit is opened or closed. In common with many other instructors, I have found this to be an unsatisfactory demonstration, as the time constant is very small and relative changes in the intensity of the incandescent lamp are difficult to observe. Furthermore, no idea is obtained of the direction of the currents and e.m.f.'s involved. I have therefore for some years used a modified circuit in which a commercial neon lamp with semicircular electrodes is substituted for the incandescent lamp.

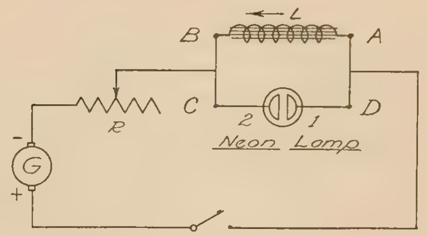

FIG. 1. Diagram of circuit.

With the switch closed and the polarity of the generator as indicated in Fig. 1, electrode *1* glows, the current being from A to B through the coil and from D to C through the lamp. When the switch is opened suddenly, the e.m.f. is induced in the coil in the same direction as the previously applied voltage and tends to prolong the current in the coil, as indicated by the arrow from A to B. The circuit is still complete through the neon lamp and the IR-drop across it must now be equal in magnitude and opposite in direction to that induced in the coil, by Kirchhoff's law; hence the polarity is reversed from that indicated and the opposite electrode *2* glows, the current now being from C to D.

It is more difficult to show that the e.m.f. induced in the coil upon closing the switch opposes the applied voltage from the generator. With an inductance of 0.60 h and resistance 6.5 ohm, the time constant is only 0.092 sec, and even a zero-centered voltmeter would indicate no apparent lag. Enough resistance should therefore be introduced at R so that the IR_L-drop across the coil in the steady state is too small to light the lamp. On closing the switch there is a momentary flash of electrode *1*, thus indicating a transient e.m.f. in the coil from B to A sufficient to light the lamp. This e.m.f. is opposite to that at the break, and to the applied voltage. Caution to the demonstrator: Keep wrist watches away from the coil, and use a long handled knife switch!

The chief value of the demonstration lies in the simplicity and familiarity of the apparatus. The same phenomena could be shown more nicely and somewhat quantitatively by means of the cathode-ray oscillograph, but the average student would lose sight of the fundamentals in a maze of apparatus.

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The Use of the High Intensity Mercury Vapor Lamp

THE new 85-w high intensity mercury vapor lamp[1] brings to physicists a source of monochromatic radiations which is so simple and inexpensive that it may, for most purposes, well replace other types in lecture room and laboratory. Its luminous output in the visible region is from five to ten times that of a Lab-arc and its intrinsic brilliance is over one hundred times as great because of capillary shape of the arc stream. In experiments or demon-

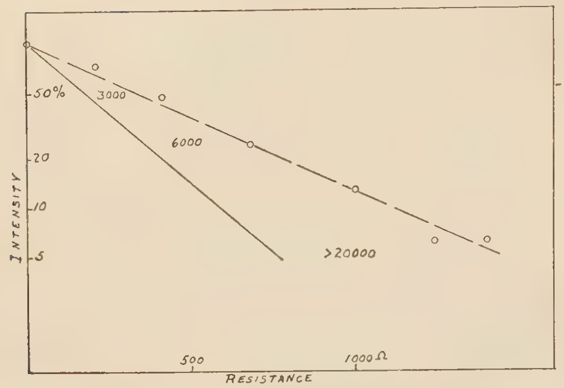

FIG. 1. Intensity *vs.* resistance in series with lamp.

strations requiring a point or line source the new lamp leaves little to be desired. Biprism fringes, Fraunhofer patterns for single and multiple slits, and the various Fresnel diffraction effects may be obtained with brilliance on a scale of magnification that eliminates any strain on the eye of the observer. In the lecture room it is possible to project monochromatic green fringes formed by a Michelson interferometer with almost as satisfactory a pattern on the screen as one obtains for the white light fringes from a carbon arc source.

The vapor pressure in the lamp is high and the lines of the spectrum are correspondingly broad. The width of line 5461A is about 3A, judged from the disappearance of the fringes in the field of a Michelson interferometer. We have found that the spectral purity may be decidedly increased by placing a resistance directly in series with the lamp in the secondary of the transformer. The intensity is correspondingly reduced and the effect is shown in Fig. 1. The solid curve is for a stock lamp burning base up and the dashed curve for a lamp ordered specially to burn base down. Both curves give the response of a Cs photo-cell to the visible portion of the radiation. The circled points are for the special lamp and show the change in the intensity of 5461A. The two lamps, though decidedly different in their response to the introduction of resistance, have about the same normal intensity and the same minimum intensity. Each arc becomes unstable if its intensity is reduced below about 5 percent of normal.

Since the normal arc has lines with widths of several angstrom units it is not feasible to use it as an interferometric source if the order of interference much exceeds 1000. The numbers in Fig. 1 which lie between the two curves indicate roughly the usable order of interference when the arc intensity has been reduced to the corresponding fraction of normal. Though the highest obtainable order falls far short of a vacuum arc it is still sufficiently great to meet most needs.

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[1] General Electric or Westinghouse type H3.

A Simple Low Power Audio-Frequency Oscillator

WHILE working with laboratory-assembled capacitance bridges, the desirability of some convenient source of audio-frequency other than the microphone hummer soon became apparent. The particular disadvantage of the hummer arises from the fact that the direct

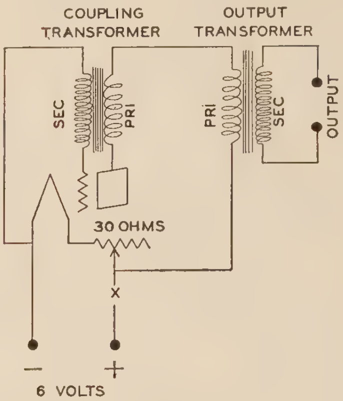

FIG. 1. Audio-frequency oscillator.

sound from the tuning fork may mask the effect produced in the bridge excited by the hummer. If the output from a vacuum-tube oscillator of audible frequency is supplied to the bridge circuit by means of an audio-frequency transformer, the only sound perceived by the observer will be that heard in the telephones. A compact form of such an oscillator employing the Hartley circuit (Fig. 1) has been devised by the author.

The special feature of this device lies in the fact that a single 6-v battery serves as the total power supply for the oscillator. The tube employed is a O1A, though any similar triode might be used. The plate supply is obtained from the voltage drop along the filament rheostat, thus eliminating the use of a B-battery. If desired, dry cells may be used as filament supply and mounted within the oscillator box. Coupling between the plate and grid circuits is accomplished by means of a 3 : 1 ratio audio-frequency transformer, the proper polarity of connection being determined by trial. If the transformer is at all satisfactory, no difficulty will be experienced in obtaining oscillations. The frequency of the oscillator may be changed by resetting the filament rheostat, although this action simultaneously

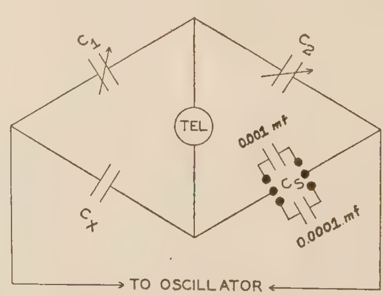

FIG. 2. Capacitance bridge.

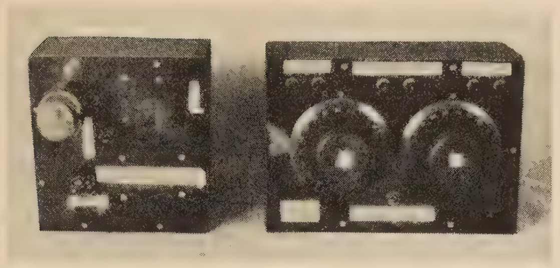

FIG. 3. Assembled oscillator and capacitance bridge.

modifies the intensity of the signal.[1] The oscillator is connected to output terminals through a transformer similar to that used as the coupling transformer.

The oscillator finds a particular application in exciting a capacitance bridge. If variable condensers replace the resistance arms of the usual form of bridge, adjustment of the bridge to a condition of balance is simplified considerably. Nernst,[2] and later Fleming and Dyke,[3] developed this idea of employing four condensers. The author has found it convenient to employ variable condensers of the type used in long wave radio receiving sets, since they possess practically a straight line calibration curve. Although the calibration curves of both ratio-arm condensers are supplied to the student, it is found that comparatively little error is introduced if the ratio of dial settings is employed rather than the ratio of actual capacitances. Either of two fixed condensers may be connected to the bridge to serve as a standard. The capacitance of the "standards" is certified by the maker to be within 5 percent of the rated value. Fig. 2 indicates the author's arrangement of the 4-condenser capacitance bridge. Photographs of the oscillator and capacitance bridge appear in Fig. 3.

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University, Mississippi.

[1] The attention of the author has been called to the arrangement of Schroer [Sch. Sci. and Math. 36, 886 (1936)] in which the frequency of a Hartley oscillator generating audio-frequencies could be changed without changing the intensity.

[2] Ann. d. Physik 60, 600 (1897).

[3] J. Inst. El. Eng. 49, 323 (1912).

The Forthcoming Indianapolis Meeting of the American Association of Physics Teachers

THE seventh annual meeting of the American Association of Physics Teachers will be held in Indianapolis, Indiana, on Monday and Tuesday, December 27–28, 1937. According to present plans, the Monday morning session will be devoted to contributed papers presented in parallel sessions; Monday afternoon, to selected committee reports and a symposium of invited papers on "College Physics in Its Relation to Pre-College Education"; Tuesday morning, to contributed papers in parallel sessions, a brief business meeting, and an invited demonstration lecture; and Tuesday afternoon, to a joint session with Section B of the A. A. A. S. and the American Physical Society. At a dinner to be held jointly with the American Physical Society, the presentation will be made of the second A. A. P. T. Award for Notable Contributions to the Teaching of Physics. The Indianapolis Athletic Club will be headquarters for the meeting. The Spink Arms Hotel, 410 N. Meridian St., across the street from the headquarters, also has good rooms with baths at $2.50 to $4 single, $4 to $7 double. There will be a registration of Association members.

Contributed papers are limited to 10 minutes. Members who wish to submit contributed papers should send the title as soon as possible to the Secretary, Professor Thomas D. Cope, Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pa. *A 150–300 word abstract of the paper, prepared in a form suitable for publication, must be in the hands of the Secretary by November 15.* Copy for the abstract must be typewritten, double spaced, and should be prepared in the same form as the abstracts which appeared in February, 1937 issue of *The American Physics Teacher*, pages 45–48.

District of Columbia Chapter of the A. A. P. T.

DEMONSTRATION experiments will constitute the program of the first fall meeting of the District of Columbia chapter of the American Association of Physics Teachers. The meeting will be held during the last week of October, on a date to be determined after teaching schedules for the fall semester are settled.

The formation of the District of Columbia chapter was authorized at the last annual meeting of the Association. The chapter officers are: E. J. Kolkmeyer, Georgetown University, president; R. L. Feldman, Roosevelt High School, secretary-treasurer; Ellis Haworth, Wilson Teachers College, and George D. Rock, Catholic University of America, members of the Executive Committee. All teachers of physics in the vicinity are invited to affiliate. Address the secretary-treasurer, Box 265, Route 1, East Falls Church, Va.

DISCUSSION AND CORRESPONDENCE

Laboratory Work in the General Physics Course for Engineering Students

If one reads the articles pertaining to physics teaching published from about 1900 to 1915, he will reach the conclusion that a rather hot controversy was raging among physics teachers and educators. There was a decided lack of agreement as to what is to be accomplished in an elementary course as well as to how to conduct a class in order to accomplish the results desired. At the time the writer began his career as a teacher, the slogan was that physics should be made "practical." Some carried this to such an extreme as to advocate, for example, that students of physics should be taught to read meters of all kinds, thus showing a very impractical notion of what is really practical.

Now it is easy to say that a subject should be practical, but quite a different thing to separate the practical into a class by itself. Usually the practical would be defined as something that the student could and would use in his future everyday life. If we take this as a criterion, much that is taught in a course in engineering would be classed as impractical. For example, it is possible that the work of an average engineer may not call for the use of the calculus.

Entering teaching as I did, in this confusion of thought as to the aims of physics instruction, I found it necessary to formulate some definite ideas of my own as to the objectives of teaching and results to be expected—some that would at least satisfy me, whether they satisfied others or not. These may be stated in few words: *Physics should be so taught that the student can use the principles in his thinking.* There can be no assurance, of course, that he will so use them, but if the teacher so conducts the course as to render this possible he will have done his duty, and explicit consideration of the practical drops out of the picture. Whatever objections some may raise to such an aim for secondary school and liberal arts physics on the grounds that the students lack the capacity to think, no such objection can be raised in the case of the student of engineering since engineering is pretty largely applied physics, and the engineer is required to think in terms of principles of physics.

The formal lecture, though not essential, is a good method of presenting principles to the student. The recitation or quiz period affords a good way to reveal the student's personal difficulties and to help him over perplexing points. But if he is to use physical principles in thinking he must be given a practical opportunity to do so while he is studying physics; and this should be done in such a way that there is an opportunity for discussion with the instructor and, perhaps, with other students.

At the University of Wyoming we have based our teaching upon these ideas as applied particularly to problem work and the laboratory. For the past seventeen years our course for engineering students has been offered for five hours credit and has consisted of three lectures or recitations, two three-hour laboratory periods, and a period in which the student worked problems under supervision. Experiments were written up in the laboratory; the laboratory period was used as a study period, not as a test period.

In the fall of 1936 the enrollment became so large that we were obliged to rearrange the laboratory periods. Our appeal to the administrative staff availed us nothing, and it was necessary to handle our own problem. We tried to avoid a reduction of the laboratory work because this would mean discarding a large amount of apparatus. So we changed the two three-hour laboratory periods to two two-hour periods run continuously in one afternoon. The result was decidedly disappointing. Although the writing-up was done on the outside, the best the students could do was about 75 percent of the usual work. Formerly we had given 16 experiments in the fall term, but the average number now covered was only 12 and this average was possible only because some of the students were ambitious enough to put in extra time. Eleven experiments were finally set as the minimum.

During the winter and spring terms we reduced the laboratory to one period a week and added one lecture period. Due to the overload in the department we dropped the problem period also. The results were surprising. Instead of doing more in the classwork as one would expect, we were unable to cover more ground in the lectures than in previous years with one less lecture period. We also found that the students were unable to answer questions in examinations that in previous years were handled easily when the topic in the questions had been covered in laboratory as well as classwork.

The final results seem to show that we have deprived our students of considerable valuable training. Dropping the problem section, of course, added something to this effect. We have omitted the problem section in other years, however, and while many students feel that there is much to be said in favor of such a section, from our experience we cannot attribute much of these results to the lack of it. There are of course other contributory circumstances such as the larger number in the class and the use of more student help.

The question of the proper weight to be given to lecture, quiz, problem work, and laboratory thus seems to have become one of economy rather than of results. Can we afford to pay the cost of effective laboratory work for the proper training of the engineering student? Or would it be better to put it the other way? Can we afford *not* to pay the cost for good training?

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Concerning Stephen Gray: 1696(?)–1736

FOR a twentieth century student to put himself back two hundred years and call upon his imagination for a correct picture of electrical science at that time is not the easiest thing in the world. From such a picture one must omit all mention of electromagnetism. The existence of electric currents must be forgotten because the work of Galvani and Volta came nearly half a century later. Electrolysis and the heating effect of electric currents were equally unknown.

In 1729, when Gray made his capital discovery, Newton had just been laid to rest in Westminster Abbey. Hawksbee, Gray and Du Fay were the leading electricians of the world. Neither Cavendish nor Coulomb was yet born. Bennett, the inventor of the gold-leaf electroscope, belonged to a still later generation. Benjamin Franklin, a vigorous youth in his twenties, had not yet acquired any large interest in electricity. The Leyden jar had not yet been invented.

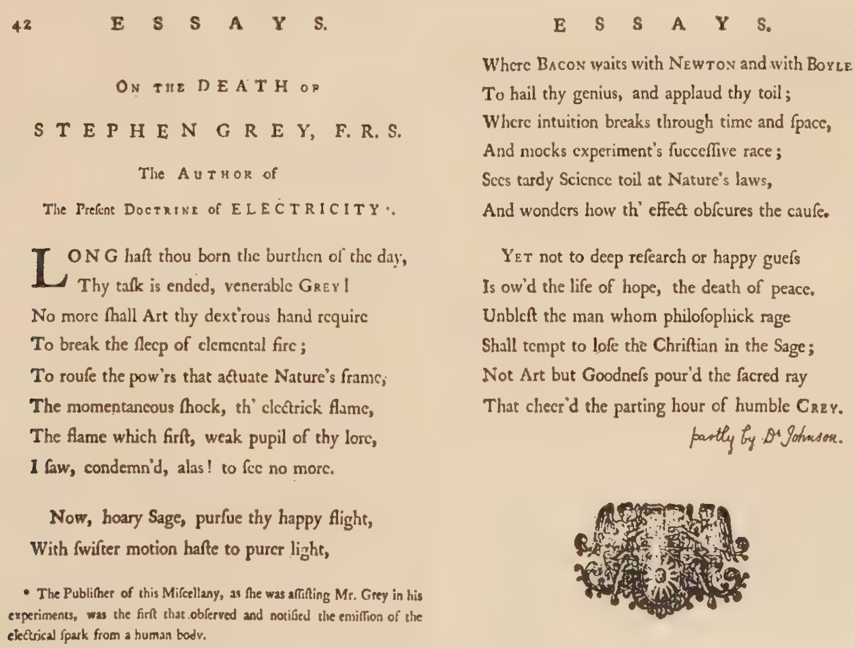
For this early picture of electrical science one has not much left but the fundamental amber phenomenon of Thales, to which von Guericke, Newton and Hawksbee had added a method of easily producing large charges; and had noticed the luminescence which accompanies the electrification of a vacuum tube, as well as the noise of the spark. William Gilbert had divided all bodies which can be rubbed into two classes, namely, those which attracted his *versorium* and those which did not. The region immediately surrounding a charged body was supposed to be filled with an effluvium, something of the order of an exhalation which is detected by the sense of smell; but the science of electrostatics was little advanced beyond the point where the Greeks left it. In fact, it was an impenetrable mystery and perhaps on the same level with the present-day state of telepathy, table-moving, and clairvoyance. The only book on the subject in the English language was Francis Hawsbee's work *Touching Light and Electricity, Producible on the Attrition of Bodies* (London, 1709).

It was into this world that Stephen Gray came and reported to the Royal Society of London that, on July 14, 1729, he had succeeded in conducting the "electric vertue" from a charged body along a pack thread to an uncharged body 765 ft. away. During these experiments with "communicative electricity" as he calls it—a name whose full significance he little dreamed of—the two following fundamental discoveries were made:

(i) All bodies can be divided into two classes—*conductors and nonconductors*—which (as Desaguliers immediately pointed out) are respectively identical with Gilbert's *nonelectrics* and *electrics*.

(ii) A conductor can be electrified, without rubbing, by merely bringing it near another charged body—the sheer phenomenon of electrostatic induction—noted but not explained.

Oddly enough we know concerning the life of this original observer almost nothing, save the fact that he was a pensioner of the Charter House. Even the date and place of his birth are uncertain. His boyhood and training are a blank. His experiments were made mostly at the country home of a friend. Gray was a pioneer and has apparently suffered the fate of most pioneers—that of being forgotten. The *Dictionary of National Biography* gives half a page to him. The thirteen pages by J. F. Corrigan in *Science*



42 ESSAYS.

ON THE DEATH OF

STEPHEN GREY, F.R.S.

The AUTHOR of

The Preſent DOCTRINE of ELECTRICITY *.

LONG haſt thou born the burthen of the day,
Thy taſk is ended, venerable GREY!
No more ſhall Art thy dext'rous hand require
To break the ſleep of elemental fire;
To rouſe the pow'rs that actuate Nature's frame,
The momentaneous ſhock, th' electrick flame,
The flame which firſt, weak pupil of thy lore,
I ſaw, condemn'd, alas! to ſee no more.

Now, hoary Sage, purſue thy happy flight,
With ſwifter motion haſte to purer light,

* The Publiſher of this Miſcellany, as ſhe was aſſiſting Mr. Grey in his experiments, was the firſt that obſerved and notified the emiſſion of the electrical ſpark from a human body.

ESSAYS. 43

Where BACON waits with NEWTON and with BOYLE
To hail thy genius, and applaud thy toil;
Where intuition breaks through time and ſpace,
And mocks experiment's ſucceſſive race;
Sees tardy Science toil at Nature's laws,
And wonders how th' effect obſcures the cauſe.

YET not to deep reſearch or happy gueſs
Is ow'd the life of hope, the death of peace.
Unbleſt the man whom philoſophick rage
Shall tempt to loſe the Chriſtian in the Sage;
Not Art but Goodneſs pour'd the ſacred ray
That cheer'd the parting hour of humble GREY.

partly by Dr Johnson.

FIG. 1. Photograph of pages 42 and 43 of Mrs. Williams' *Miscellanies*.

Progress, Vol. 19 (1924) contains little, if any, more biographical information than is contained in the half-page of *D. N. B.*

A few weeks ago, while enjoying the long postponed pleasure of reading Boswell's *Life of Johnson*, my eye lighted upon a reference to a poem "On the Death of Stephen Grey, the Electrician," by Mrs. Anna Williams. I went at once to my ever helpful colleague, Dr. T. W. Koch, of the Deering Library, who promptly secured a copy of this poem from a volume by Mrs. Williams, entitled *Miscellanies*, now in possession of the New York Public Library. So fundamental is Gray's discovery and so scanty our acquaintance with him that even these few rhymed couplets (Fig. 1), written by one who knew and helped him, may be of interest to teachers of physics and to students of electricity.

With reference to the note at the end, it will be remembered that Dr. Johnson (1709–1784) had the generous habit of writing prefaces and dedications for his friends and often rendered first aid to ailing manuscripts, sometimes giving surgical assistance, sometimes only medicinal and curative.

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Notation for the Moment of a Vector

WITH rectangular axes $OXYZ$ (unit vectors $\mathbf{i}$, $\mathbf{j}$, $\mathbf{k}$), let $\mathbf{a}(a_x, a_y, a_z)$ be any vector localized in a line, and let $\mathbf{r}(x, y, z)$ be the position, referred to O, of any point in the line of $\mathbf{a}$. Then the moment of $\mathbf{a}$ about O is defined by

$$\mathbf{r}\times\mathbf{a}\equiv\mathbf{i}(ya_z-za_y)+\mathbf{j}(za_x-xa_z)+\mathbf{k}(xa_y-ya_x),$$

and the moment of $\mathbf{a}$ about OX is defined by

$$\mathbf{i}\cdot\mathbf{r}\times\mathbf{a}\equiv ya_z-za_y.$$

The object of this note is to draw attention to the desirability of a convenient shorthand notation for the foregoing quantities, and to suggest a possible notation. It is surprising that while there exists a recognized notation (a_x) for the component of $\mathbf{a}$ parallel to the x axis, no corresponding form for the moment of $\mathbf{a}$ about the x axis has gained acceptance.

Of a satisfactory notation we require that it indicate, without ambiguity or redundancy, the quantity which it denotes. This requirement is not fulfilled by the foregoing symbolic definitions since, to indicate the moment of a vector about an origin (or axis), it is sufficient to indicate the vector and the origin (or axis), whereas the foregoing definitions, in addition, refer specifically to a point in the line of the vector. The following notation is accordingly suggested:

$${}^{O}\mathbf{a}\equiv\mathbf{r}\times\mathbf{a},\quad {}^{x}a\equiv\mathbf{i}\cdot{}^{O}\mathbf{a}\equiv ya_z-za_y.$$

Examples are: (a) The angular momentum theorem for a system of particles,

$$\sum{}^{O}(m\mathbf{v})={}^{O}\{(\sum m)\bar{\mathbf{v}}\}+\sum{}^{G}(m\mathbf{v}')$$

or

$$\sum{}^{x}(mv)={}^{x}\{(\sum m)\bar{v}\}+\sum{}^{x'}(mv'),\quad \text{etc.};$$

(b) The conditions for equilibrium of a rigid body,

$$\sum\mathbf{F}=0,\quad \sum{}^{O}\mathbf{F}=0$$

or

$$\sum F_x=0,\quad \sum{}^{x}F=0,\quad \text{etc.}$$

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Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

13. Ph.D. Cornell. Age 31, married, 2 children. 4 yr. college teaching, 5 yr. full-time research in x-rays. Primarily interested in college teaching and research. Hobbies: photography, geology, music.

14. Ph.D. Chicago, B.S. Bradley Polytechnic, with minors in math. and chem. Age 25, married. 4 yr. laboratory and teaching assistant, Chicago. Research, Faraday effect at high frequencies.

15. Ph.D. Iowa State, B.S. in E.E. Minnesota. Age 33, unmarried. 5 yr. sales and research engineer, 4 yr. teaching fellow, physics. Research, effect of gas on metal surfaces used for electron recording, etc. Interested in teaching.

16. Ph.D. Indiana. Age 38, married, 2 children, 6 yr. college teaching, Research in acoustics. Trained for teachers college or university position. Interested in teaching, laboratory development, and research.

20. Ph.D. Univ. of Minnesota; S.B., S.M., M. I. T.; 1 yr. grad. work, Univ. of Iowa. Age 38, married, 2 children, 17 yr. teaching experience in universities, colleges and technical schools, including 10 yr. head of department. Interested in progressive undergraduate and graduate teaching and research, including mathematical physics.

Any member of the American Association of Physics Teachers who is not employed in a capacity that makes use of his training in physics may register for this appointment service and have a "Position Wanted" announcement published without charge.

RECENT PUBLICATIONS AND TEACHING AIDS

Laboratory Manuals

Outline of Laboratory Physics. ALFRED H. WEBER, professor of physics, St. Joseph's College. 86 p., 71 fig., 21×28 cm. *John S. Swift Co.*, planographed edition, paper $1.50. The theory of each of the 63 experiments in this manual is given only in brief outline, for the author believes that experiments should be discussed in detail in the lecture room, so as to link the lecture and laboratory work as closely as possible. Many of the instructions for the experiments are made specific, on the ground that this is necessary in a first course if proper laboratory technics are to be developed. Calculus methods are used in a few of the experiments, but may be omitted if desired. An examination copy of the manual can be obtained from the author.

Laboratory Manual of Physics. Ed. 5. D. A. WOODBURY AND C. W. JARVIS, Ohio Wesleyan University, and H. P. KNAUSS, Ohio State University. 270 p., 128 fig., 38 tables, 20×27 cm. *R. G. Adams & Co.* (Columbus, Ohio), paper, $2.25. The 87 experiments in this carefully planned manual are designed for students who have all varieties of interests other than engineering. Emphasis is placed on the experimental basis of scientific knowledge, and on fundamental principles and laws. The authors believe that experimental skill may be a by-product, but that emphasis on it belongs in advanced courses. In the present edition, a uniform presentation for all the experiments and topography patterned after the publications of the American Institute of Physics have been adopted to make the directions easy to read. Most of the drawings are new. The manual is loose-leaf and a supply of graph paper and blank tables is furnished with it. The 48-page introduction, which contains mathematical and physical tables, and concise discussions of experimental methods, graphical technics, errors, the design and use of important instruments, etc., is also available as a separate pamphlet under the title, *Guide for Experimental Physics* (60 cts), for use in laboratories where mimeographed directions are prepared locally.

Intermediate Textbooks

The Physics of Electron Tubes. L. R. KOLLER, Research Laboratory, General Electric Company. Ed. 2. 251 p., 84 fig., 16 tables, 15×23 cm. *McGraw-Hill*, $3.00. A clear presentation of the fundamental phenomena involved in the operation of electron tubes, gas-filled relays, and photoconductivity and photovoltaic cells. Consideration is omitted of external circuit conditions, which are amply discussed elsewhere. The numerous developments since the appearance of the first edition (1934) have been taken into account by expanding the discussion of many of the topics and by adding brief sections on electron optics, secondary-emission multipliers, ignitrons, and positive-ion emission. Lists of problems and references accompany each chapter.

An Outline of Atomic Physics. OSWALD H. BLACKWOOD, ELMER HUTCHISSON, WILFRED N. ST. PETER, GEORGE A. SCOTT, AND ARCHIE G. WORTHING, of the University of Pittsburgh; THOMAS H. OSGOOD, University of Toledo; AND ARTHUR E. RUARK, University of North Carolina. Ed. 2. 423 p., 210 fig., 23 tables, 15×23 cm. *Wiley*, $3.75. This successful textbook, which first appeared in 1933, provides a survey course in modern physics for undergraduates who have had a year of general college physics. A chapter on nuclear structure has been added to the revised edition, and changes have been made throughout the text to bring it up-to-date and to clarify the presentation. In the revision the authors were guided by suggestions and criticisms obtained by sending a questionary to the many teachers who have used the book.

Advanced Textbooks and References

An Introduction to Nuclear Physics, N. FEATHER, university lecturer in physics and Fellow of Trinity College, Cambridge. 223 p., 24 fig., 22 tables, 14×22 cm. *Cambridge University Press* and *Macmillan*, $3. This clear and well-written introduction to the chief ideas needed for an understanding of current research in nuclear physics should be of particular value to students who are beginning research in the field. Experimental aspects and the historical background are emphasized. Important results are given in tabular form. The first third of the book traces the growth of the need for the concepts *nuclear atom* and *atomic-nucleus-possessing-internal-structure*, and the remaining chapters summarize the developments which followed upon the acceptance of this general scheme of interpretation.

The Theory of Metals. A. H. WILSON, Fellow of Trinity College, Cambridge. 280 p., 30 fig., 10 tables, 14×22 cm. *Cambridge Univ. Press* and *Macmillan*, $5. The great advances made in the electron theory of metals during the past decade have established so many of the underlying principles that for some time to come we may expect to see refinements of the theory rather than entirely new developments; hence the timeliness of this critical theoretical survey of the electronic properties of solids, with its emphasis on the assumptions involved and the difficulties that still remain. In the first quarter of the monograph, the general theory and its history are given; in the remainder, the theory is applied to equilibrium properties, optical properties, conduction, and the mechanism which produces resistance in a metal. A brief summary of the Fermi-Dirac statistics and a sketch of surface phenomena appear in appendexes.

Elements of Probability. H. LEVY, professor of mathematics, AND L. ROTH, assistant lecturer in mathematics, Imperial College of Science and Technology. 210 p., 25 fig., 14×22 cm. *Oxford Univ. Press*, $5.00. The authors of this

interesting book point out that in the past various writers have approached the subject of probability from very diverse angles—as a branch of symbolic logic, as a series of empirical conclusions, as a branch of pure mathematics, as a description of a state of mind—and that little attempt at unification has been made. Their view in this book is that probability is an essential of scientific method and that a probability estimate, however it is approached, has to be seen and interpreted as a guide in scientific procedure; hence the various approaches are in reality partial aspects of the same topic, where in each case the form of analysis has been decided by the particular purpose for which the treatment has been attempted. In the earlier portions of the book, simple considerations of mathematical probability and its linkages with statistics are treated in a form suitable for nonmathematical students.

Measurement of Radiant Energy. 446 p., 224 fig., 33 tables, 15×23 cm. *McGraw-Hill*, $5. This important and useful compilation covers the concepts, laws, and constants of radiation, sources of radiation and the care to be taken with them in measurements, the analysis of radiation, and methods of measuring radiation together with the precautions necessary for accurate work. A comprehensive list of references accompanies each of the 14 chapters. The book was prepared under the direction of a committee of the Division of Physical Sciences, National Research Council, which consisted of W. E. Forsythe, who acted as editor, Herbert E. Ives, and Arthur C. Hardy. The following 21 specialists contributed the various chapters: C. G. Abbot, E. Q. Adams, L. B. Aldrich, E. F. Barker, B. T. Barnes, W. W. Coblentz, P. H. Dike, G. Fassin, W. E. Forsythe, K. S. Gibson, G. R. Harrison, H. E. Ives, L. A. Jones, L. R. Koller, H. F. Kurtz, A. H. Pfund, B. J. Spence, D. C. Stockbarger, A. H. Taylor, W. Weniger, and A. G. Worthing.

Relativity Theory of Protons and Electrons. Sir Arthur Eddington, Plumian professor of astronomy and experimental philosophy, University of Cambridge. 342 p., 18×26 cm. *Cambridge Univ. Press.* and *Macmillan*, $5.50. The author's *The Mathematical Theory of Relativity* (1924) treated the usual macroscopic theory of relativity. The present work extends the treatment to cover microscopic phenomena by giving an account of the investigations in the borderland between the relativity and quantum theories, begun when Dirac in 1928 furnished the first connecting link between the two theories with his linear wave equation of the electron. The central problem of the work is to ascertain the conditions that fix the mass and electric charge of protons and electrons; but it is also shown in detail how the conceptions of the relativity and quantum theories can be harmonized for the solution of specific problems which would be outside the range of either theory separately. Actually, this harmonization is effected by a profound modification of the quantum mechanics, with general relativity purposely kept unaltered. Half of the book is given to wave-tensor calculus; the rest, to physical applications, including the Riemann-Christoffel tensor, the mass-ratio of the proton and electron, standing waves, the cosmical problem, electric charge, and the exclusion principle. The author regards his theory as purely deductive—as based on epistemological principles and not on physical hypotheses; and he concludes that, "unless the structure of the nucleus has a surprise in store for us . . ., there is nothing in the whole system of laws of physics that cannot be deduced unambiguously from epistemological considerations."

Atomic Structure of Minerals. W. L. Bragg, Langworthy professor of physics in the Victoria University of Manchester, 302 p., 145 fig., 13 tables, 15×23 cm. *Cornell Univ. Press*, $3.75. Crystallography in the past was developed mostly by mineralogists; but x-ray analysis of crystal structure has altered the position and present developments in the science are due mainly to physicists, for the experimental technic is of a type to which they are accustomed. The author of the present authoritative review of investigations in this field points out that the structures of nearly all the important types of minerals are now known and, while many points still await investigation, a summary of their general features can be made which leads to a much deeper understanding of the properties of minerals, and a more scientific basis of classification, than formerly was possible. The book should be of interest not only to mineralogists but to many physicists because of the interpretations given of the physical properties of minerals in terms of internal atomic arrangements.

A Commentary on the Scientific Writings of J. Willard Gibbs. Vol. 1, **Thermodynamics**; Vol. 2, **Theoretical Physics.** 765 p., 625 p., 15×23 cm. *Yale Univ. Press*, $10. These volumes have been prepared under the auspices of Yale University for the purposes of honoring the memory of J. Willard Gibbs and of providing much needed supplements for use in the study of the original text of Gibbs' writings. Each of the two volumes supplements the like-numbered volumes of *The Collected Works of J. Willard Gibbs.* Volume 1 deals with Gibbs' highly original and beautiful work on thermodynamics, particularly the great paper on "The Equilibrium of Heterogeneous Substances," which served to bring generalized thermodynamics to a level of perfection and comprehensiveness comparable to that which had previously been reached by dynamics in the hands of Lagrange and Hamilton. Because the generality and abstract nature of these papers has made an understanding of them difficult for students, particularly students of chemistry, the present volume has been designed to provide interpretative and explanatory discussions of the work, and examples of its application to modern problems, thus smoothing the path for students and making Gibbs' methods and results more generally intelligible and available. The various articles in this volume were prepared by D. H. Andrews, J. A. V. Butler, E. A. Guggenheim, H. S. Harned, F. G. Keyes, E. A. Milne, G. W. Morey, J. Rice, F. A. H. Schreinemakers, and E. B. Wilson. Volume 2 deals in part with optics, vector analysis and multiple algebra, and certain physical

aspects of thermodynamics; but the greater part of it is concerned with Gibbs' masterly and difficult treatise on statistical mechanics and with the relation of his statistical ideas to subsequent developments of physics. The articles in this second volume were contributed by P. S. Epstein, A. Haas, L. Page, and E. B. Wilson. Professors Haas and F. G. Donnan edited the volumes.

History and Biography

Marconi—The Man and His Wireless. Orrin E. Dunlap, radio editor of *The New York Times.* 381 p., 15 photographs, 15×21 cm. *Macmillan*, $3.50. An exceptionally interesting, popular account of Marconi and his life-work, prepared by an experienced writer and read in final proof by Marconi himself, shortly before his death.

Men of Mathematics. E. T. Bell, professor of mathematics, California Institute of Technology, 613 p., 49 photographs and diagrams, 16×24 cm. *Simon and Schuster*, $5. Any physicist who fails to read this popular account of the lives and achievements of the great mathematicians from Zeno to Poincaré is missing something. The emphasis is on personalities and idiosyncrasies, as well as on achievements; and the style is often ironic and witty, and sometimes extremely frank. The whole book is replete with ideas that make it delightful and stimulating reading.

Recollections and Reflections. Sir J. J. Thomson, Master of Trinity College, Cambridge. 460 p., 15×23 cm. *Macmillan*, $4. An absorbing account of incidents in the author's work on gaseous conduction and the discovery of the electron, of long association with the Cavendish Laboratory during a great era of physics, of friendships, often as pupil, teacher, or colleague, with most of the outstanding physicists of the time, of visits to America, of views on teaching and on education in general. Any autobiography of a physicist of the standing and background of J. J. Thomson is sure to be a useful historical document; and the present one is also so human, informal, and intimate in style that any physicist or student of physics should find it most enjoyable as well as profitable reading.

General Education

The Effective General College Curriculum as Revealed by Examinations. Committee on Educational Research of the University of Minnesota. 443 p., 15×23 cm. *Univ. of Minnesota Press*, $3. The development, objectives, and operation of the general college program instituted at the University of Minnesota in 1932 is described. About half the space is given to discussions of 9 specific areas of instruction; for example, a 37-page chapter, by Palmer O. Johnson, outlines the courses in physical science and gives examples and results of the tests used in this area to measure various aspects of student growth. In another chapter the technical terms which occur in the science courses are listed. Incidentally, there are some 1775 physical science and technologic terms, and 1840 biologic terms; and the numbers of terms for physics and chemistry are roughly the same.

Books for Secondary and Elementary Schools

Workbook and Laboratory Manual in Physics, Hallie F. Turner, Eastside High School, Paterson, N. J. 288 p.; 82 fig., 20×27 cm. *College Entrance Book Co.*, paper. A manual of 71 experiments, with many study-questions and short-answer tests, for use with any secondary physics text. Professor C. A. Culver of Carleton College was one of the editors.

Science Experiences with Home Equipment. C. J. Lynde, professor of physics, Teachers College, Columbia University. 241 p., 200 fig., 13×20 cm. *International Textbook Co.* (Scranton, Pa), $1.25. Two hundred exceedingly simple physical "experiences" for grade children that can be had with such homely paraphernalia as tables, chairs, bottles, and hairpins. The book should interest children and be helpful to elementary school teachers, particularly those whose experiences with physical phenomena are meager.

Science in the Elementary School. W. C. Croxton, State Teachers College, St. Cloud, Minnesota. 463 p., 15×23 cm. *McGraw-Hill*, $3. This book for elementary school teachers should serve the worthy purpose of helping to encourage more and better instruction in the natural sciences in the lower grades of schools. The first quarter of the book is devoted to a discussion of science teaching in the grades; the remainder, to good outlines, with discussions and references, of 110 science projects suitable for children.

Unit Outlines in Physics. Theodore Colen, Science editor, College Entrance Book Co., and Barclay M. Newman, head of science department, Brooklyn Academy. 304 p., many diagrams, 13×19 cm. *College Entrance Book Co.* A review or supplementary outline which follows in its treatment the basic requirements of various important college entrance syllabi. Many solved examples, questions and problems are given. Important formulas are emphasized strikingly by having them appear in "reverse cuts"; that is, in white against a black background. Although some of the statements are loose, some incorrect, and others meaningless—not just "simply expressed"—the outline is not nearly so bad in these respects as some of the textbooks of secondary school grade that have been published recently.

Pamphlets

Exide Storage Batteries. Forms 1369 and 2480. *Electric Storage Battery Co.* (Allegheny Ave. and 19th St., Philadelphia, Pa.), gratis. Two booklets entitled, "Fundamentals of a Storage Battery" and "Instructions for Installing and Operating Storage Batteries."

Edison Nickel-Iron-Alkaline Storage Batteries. Monograph III. 38 p., 49 fig., 15×23 cm. *Thomas A. Edison, Inc.* (Storage Battery Div., West Orange, N. J.), gratis. A description of the construction, operation, and manufacture of the Edison cell. Prepared especially for teachers.

Charts and Posters

Edison Cell Wall Chart. 31×48 cm. *Thomas A. Edison, Inc.* (Storage Battery Div., West Orange, N. J.), gratis. A cross-sectional view, with details of construction, of an Edison nickel-iron-alkaline secondary cell.

Battery Lecture Wall Chart. 104×208 cm. *Electric Storage Battery Co.* (Allegheny Ave. and 19th St., Philadelphia, Pa.), gratis. Shows the parts of a secondary cell and gives the chemical equations for the charge and discharge periods.

Miscellaneous Books

The Newer Alchemy. Lord Rutherford, Cavendish professor of experimental physics, University of Cambridge. 75 p., 21 fig. and plates, 12×19 cm. *Cambridge Univ. Press* and *Macmillan*, $1.50. A brief nontechnical account of modern work on the transmutation of the elements, of how it is accomplished and what it means.

Time and Its Mysteries. Series 1. 112 p., 6 fig., 14×22 cm. *New York Univ. Press*, $2. These four nontechnical lectures are the first of a series on the concepts of time and on timepieces to be given at New York University on the James Arthur Foundation. The titles are: *Time*, by R. A. Millikan; *Time and Change in History*, by J. C. Merriam; *On the Lifetime of a Galaxy*, by Harlow Shapley; and *Beginnings of Time-Measurement and the Origins of Our Calendar*, by the late J. H. Breasted. The first lecture appeared originally in Professor Millikan's book, *Time, Matter and Values* (1932); the last, in the October, 1935 issue of *Scientific Monthly.*

Electrical Signs of Nervous Activity. Joseph Erlanger, professor of physiology, Washington University, and Herbert S. Gasser, director, The Rockefeller Institute for Medical Research. 231 p., 113 fig., 15×23 cm. *Univ. of Pennsylvania Press*, $3.50. A technical summary of modern work on nerve currents is provided by this series of lectures given under the auspices of the Johnson Foundation of Medical Physics. The chapter headings are: Analysis of the compound action potential of nerve, Comparative physiological characteristics of nerve fibers, Some reactions of nerve fibers to electrical stimulation, Sequence of potential changes, and The excitability cycle. Other books in this series are A. V. Hill's *Adventures in Biophysics* ($3), on the applicability of physical methods to biologic and medical problems, and E. D. Adrian's, *The Mechanism of Nervous Action* ($2), on the electrical studies of the neurone for which the author received the Nobel Prize in Medicine.

Précis de Physique. G. Simon, professor in the faculty of sciences of Dijon, and A. Dognon, professor of the faculty of medicine of Paris. 1087 p., 14×19 cm. *Masson et Cie.* (120, Boulevard Saint-Germain, Paris), 100 fr. A textbook on general physics, with a 50-page mathematical introduction containing sections on analysis, the calculus, vectors, probability, etc. Because the text is comprehensive and yet relatively elementary, it should be very useful to American students who wish to improve their reading knowledge of technical French.

Meeting of the Physicists of Upper New York State

A MEETING of physicists of upper New York State will be held at Cornell University on Saturday, November 6. All interested physicists are invited to attend the following program, which will begin at 10 A.M.:

Address of Welcome. President Edmund E. Day, *Cornell University*

A Quarter Century of Progress in Physics. L. A. DuBridge, *University of Rochester*

Physical Problems of Industrial Radiography. Herman E. Seemann, *Eastman Kodak Company*

Cooling an Automobile Engine. L. P. Saunders, *General Motors Company*

The Theory of Electrical Measuring Instruments. F. C. Bobier, *General Electric Company*

Abrasives and Their Uses. E. T. Hager, *Carborundum Company*

Physics in the Small College. Paul F. Gaehr, *Wells College*

At this meeting action will be taken on the question of whether an upper New York State section of the American Physical Society shall be formed. The chairman of the committee for the meeting is Professor P. I. Wold, Union College.

Truth suffers herself to be courted, but she has evidently no desire to be won. She flirts at times disgracefully. Above all, she is determined to be merited, and has naught but contempt for the man who will win her too quickly. And if, forsooth, one breaks his head in his efforts of conquest, what matter is it, another will come, and Truth is always young. At times, indeed, it really seems as if she were well disposed towards her admirer, but that admitted—never! Only when Truth is in exceptionally good spirits does she bestow upon her wooer a glance of encouragement. For, thinks Truth, if I do not do something, in the end the fellow will not seek me at all.

—Ernst Mach, *Scientific Lectures.*

DIGEST OF PERIODICAL LITERATURE

Demonstrations

A unique density, nonmiscibility demonstration. R. E. Dunbar; *J. Chem. Ed.* **13**, 589, Dec., 1936. The differences in density of four common liquids, the nonmiscibility of any combination of these liquids, and their buoyancy as expressed by Archimedes principle can be conveniently demonstrated as follows. Roughly equal volumes of mercury, dichloroethyl ether, water, and oil are placed in a hydrometer jar or wide-mouthed bottle, whereupon each liquid takes its position from the bottom to the top of the vessel in the order named. A piece of gold or platinum placed in the jar sinks to the bottom; a brass weight or coin floats on the mercury surface; a piece of ebony, on the ether; a piece of oak wood, on the water; and a cork, on the oil. After thorough mixing of the contents, with the mouth of the vessel tightly closed, each liquid and object eventually returns to its original position, since no two of the liquids are miscible one in the other. The assembled exhibit may be preserved indefinitely.

History

The origin of Fahrenheit's thermometric scale. J. N. Friend; *Nature* **139**, 395–8, Mar. 6, 1937. A recently discovered letter of Fahrenheit to Boerhaave shows that Fahrenheit did not arbitrarily assign the numbers 32 and 212 to the freezing and boiling points of water, but that these were mere incidents in his system. The fixed points which he chose were the temperature of a mixture of ice and sal ammoniac, which he called 0°, and blood temperature, which he called 96°. Most of Fahrenheit's thermometers were intended for meteorological purposes, and apparently he chose as his zero the lowest temperature then available so that all meterological readings would be positive. The boiling point of water he probably considered as too high for the upper fixed point for meterological purposes. As for the size of the degree, Fahrenheit adopted Roemer's system, in which the interval between the fixed points was divided into $22\frac{1}{2}$ parts. At first Fahrenheit divided each of Roemer's degrees into 4 parts, which gave 90° for blood temperature and 30° for the ice point. Later he found it more convenient to call blood temperature 96°, probably because it is divisible not only by three but my multiples of two, and thus the ice point became 32°. The decimal system was then not in general use in scientific work.

General Physics

Physics and the detection of crime. L. C. Nickolls; *J. Sci. Inst.* **14**, 1–8, Jan., 1937. Only in recent years has the value of the sciences in the elucidation of crime been realized and even now they are utilized more often in preparing a case for court than in the initial search for the criminal.

The extension of vision through the use of ultraviolet and x-radiation is invaluable. Seminal stains on fabrics fluoresce in ultraviolet light and can be marked for subsequent identification, thus eliminating detailed search of fabric surfaces. The use of chemical eradicators and invisible inks can also be detected. With x-rays, the interior of suspected parcels or opaque objects can be examined.

Microscopes are invaluable in the examination of debris from pockets or the cuffs of trousers, of ink removed from documents with a needle-point pipette which does not damage the document, and of papers whose fibers have been disturbed by mechanical erasure. A microscope with a polarizer reveals minute scratches on a metal surface, because the reflected glare from the metal is eliminated. A comparison microscope, for observing two objects in the same field of view, is used to compare hairs, bullets, etc. Since photomicrography is an essential part of the illustration of such scientific evidence in court, all the microscopes in the crime detection laboratory are equipped for taking photomicrographs.

Photography is widely employed, but its most interesting use is in the examination of documents, works of art, stamps, and paper. The ideal is to eliminate background and bring out the subject required as a black figure on a white background. This is accomplished with light filters. When ink yellowed with age or chemical treatment is photographed on a process plate through a blue filter, the photograph shows almost as much contrast between the writing and the paper as did the document when it was new. Added words or emendations on a document may also be detected, for two inks which appear to have almost the same tint to the naked eye are often sharply differentiated when photographed with suitable filters.

Two objects may appear quite different when photographed with ultraviolet radiation, although to the eye they may appear to be identical in color. For instance, if one object reflects ultraviolet and red, and the other reflects only red, the two will not have the same appearance in the photograph. If it is desired to illuminate an object with ultraviolet radiation alone, a filter of Wood's glass is placed between the object and the light source. Finger prints on a highly colored surface, such as a fruit tin, can thus be photographed; for such a surface generally reflects ultraviolet radiation uniformly and, if the finger print has been powdered with a substance which absorbs the ultraviolet, the photograph will show it in black on a white background almost free from the interfering color scheme.

Fluorescence radiation is used to detect chemical eradicators and physiological fluids, and to decipher letters written in invisible ink. The camera must be screened from everything except the fluorescence radiation. Accord-

ingly, the ultraviolet source is screened with Wood's glass to remove the visible light, and a suitable filter is placed in front of the camera lens to remove the ultraviolet radiation.

Infrared photography is limited in its utility to two main types of circumstances. The technic, of course, is simply to illuminate the object with a source strong in infrared radiation and to have a screen in the optical path that will remove the visible light. There is a difference between ultraviolet and infrared photography that determines which is likely to be applicable in any particular case; namely, in ultraviolet radiation practically all visual blacks appear black while visual colors may vary from black to white, whereas in infrared radiation the reverse is true, blacks varying from black to white while visual colors are practically all white.

The second use of the infrared arises from the fact that the rays penetrate haze, skin, paper, and other translucent materials. A letter in an envelope can be photographed with infrared distinctly enough to be read. The ink left in paper after mechanical erasure can be photographed; thus while ultraviolet photography records chemical erasures on documents, the infrared reveals mechanical erasures.

Photography with oblique lighting, though simple, often gives important results. For example, the small indentations caused by the pressure of a writing instrument upon paper, when illuminated at grazing incidence, appear in the photograph with hills bright and valleys dark.

As for spectroscopy, a quartz spectrograph may be used to examine materials available in only minute quantities, especially when it is desired to show that two samples are identical as when specks of paint from a jemmy are to be compared with paint from a door. No attempt is made to determine the exact frequencies of the lines observed and this saves considerable time. The lines are orientated with respect to some standard spectrum, enough lines are identified to determine the general constituents of each sample with certainty, and then the spectra of the two samples are compared. The identification of the constituents is essential, not only to determine the nature of the samples, but to ascertain whether any of these constituents is sufficiently uncommon to give any value to the similarities of the samples. For example, the white paint from a jemmy was found to be identical with the paint from a door which had been forced; but all the lines were lead lines and white-lead paint is not distinctive enough to make this evidence of much value. In another case, however, two pieces of watch chain having identical spectra were also found to have certain distinctive constituents in common, and hence the two pieces probably were once parts of the same chain. Much research has been necessary on the frequency of occurrence of various impurities in materials of everyday use in order to determine whether the presence of certain ingredients in a sample distinguish it sufficiently for purposes of crime elucidation.

Spectroscopy in the visible region is used chiefly in identifying dyestuffs, such as is present in ordinary blue-black ink. With the use of a microspectroscopic head, a drop of ink dissolved off a document can be compared microscopically with a sample of suspected ink.

Even the finest tools have an edge that consists of a series of peaks and troughs, and when the edge is pressed over a smooth surface, characteristic marks result. The identification of scratches on an article with the scratches produced by a suspected tool is sufficient to confirm that the tool was used on the article. The drawbacks are the common occurrence of multiple scratches due to several applications of the tool to the same place, and the possibility that the edge of a tool will be altered by a hard surface so that it does not afterwards produce the same scratches. Scratches are compared photographically, it being essential to maintain absolute constancy of magnification.

One of the most common ways to mark an article is to punch a serial number on it, and hence the commonest way of destroying its identity is to file off the serial number. Much work on this problem has been done by the National Physical Laboratory and their technic is now employed in a form modified by accumulated experience. Its basis lies in the fact that punching a number in metal does not remove any metal but does compress and alter it. Consequently, even after the number is filed away there remains an area of distorted metal which follows the contours of the original punch work. With suitable etching of the surface, the area may be brought into relief against the background of unpunched metal. Unless the right reagent is used, the specimen may be spoiled, and there are many different metals requiring a variety of reagents. Failure in the use of this method is about 5 percent, and is diminishing. The method ordinarily is of no use in the case of cast or engraved numbers, although engraved numbers on plated articles sometimes yield good results. A considerably modified method is used successfully with wood, leather, Bakelite, and other materials.

It is often important to determine from which side a pane of glass was broken. In the usual fracture, the glass bulges and then cracks radially from the center of impact. Examination of the edge of one of the radial cracks will reveal a series of hyperbolic striations which start from the side of impact. Following the radial cracking, the tongues of glass are bent farther, with the curvature in the reverse direction from what it was originally. Finally the tongues break off concentrically round the center and the edge shows hyperbolic striations starting from the side opposite to the side of impact.

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CONTENTS

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